Fall 11-29-2021

Metacognition and Modeling in Chemistry Instruction

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by

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A Dissertation

Presented in Partial Fulfillment of Requirements for

the Degree of Doctor in Education

In

Secondary Chemistry Education

In the

Bagwell College of Education

Kennesaw State University

Kennesaw, Georgia

November 29, 2021

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Acknowledgements

I would like to thank my family for encouragement and support throughout this journey. I am grateful to my mother, Cornelia Laird and my father, Dr. Earl Laird, for instilling in me self-discipline, a strong work ethic and the drive to achieve. I am grateful to my siblings, Jennifer Bartholomew, Sara Irby, Kathleen Hogue and Lee Laird, for cheering me on to this accomplishment. I could not have completed this arduous undertaking without the constant support and kind forbearance of my children, Ferrill Clark, Taylor Cain, Jarred Cain, Kathryn Ray, Nathan Cain and Harrison Cain. It is they who have endured with me in the grind of the journey and spurred me on with their gracious patience and inspiring rally.

I am ever grateful to the leadership and the uplifting support of my dissertation committee chair, Dr. Mei Lin Chang; she was a bright light beckoning me on at every juncture of the path and bringing expertise to the rescue as needed. Dr. Michelle Head, also on the committee, started me down this road and believed I could walk it with success; she set before me challenges that deepened my understanding of two complex topics. Dr. Rachel Gaines, also on my committee, was an immense and providential source of guidance during the uphill climb of the dissertation. To each one, who fulfilled their roles with grace and excellence, I am grateful.

This work is dedicated to my children, Ferrill, Taylor, Jarry, Kathryn, Nate and Harry, because the raising of my children made me into a person who could take on a difficult goal late in life and finish it. May you each become fully who you were created to be. Thanks be to God for grace and goodness to set before me a new path and give me strength, perseverance and capability to walk it. To Your glory, I have earned new letters.

Abstract

The purpose of this research was to examine the interplay between science modeling, a science practice, and direct instruction in metacognition. The quasi-experimental study was designed to investigate how students' skill in science modeling was bolstered by the fortification of increased metacognitive skill and how science modeling and metacognitive guidance augmented the acquisition of chemistry content. Further, perceptions of metacognitive value and of metacognitive thinking processes were appraised in conjunction with the direct metacognitive cultivation treatment. Data was collected from 48 students in honors chemistry class at a large suburban high school in the Southeastern United States (control group, n=27; experimental group, n=22). Students in the experimental group were introduced to metacognition through direct instruction and taught modeling skills alongside metacognitive reflection; thus, direct cultivation of metacognition was contextualized in the development of modeling skill. Achievement data and survey on perceptions of the metacognitive thinking process were collected. The results showed no significant differences between control and experimental groups in the survey nor for learning gains from the overall achievement data. On the other hand, significant differences between groups were revealed for performance measures of rubric scores on models and summative scores on model construction. A positive relationship was revealed between value of metacognition and metacognitive thinking processes for the experimental group. The results of the research are significant for chemistry teachers in the skill development of modeling and potential in bolster metacognition.

KEYWORDS: chemistry modeling, particulate drawings, submicroscopic representations, SEPs, solution chemistry modeling, metacognition, direct instruction of metacognition, contextualized metacognition in content skills

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Chapter One: Introduction

When I embarked on Masters' level of study at the University, I was not a novice instructor rather a veteran of 20+ years in the classroom. Little did I know that two concepts acquired under the tutelage of two masterful professors would form the tandem areas of study foundational to my doctoral study. Learning about the potential of metacognition and the power of modeling forcefully impacted my instructional practices. When I stood at the precipice of determining research topics for doctoral study a few years later, these topics, transformational in my paradigm of teaching, would call. Metacognition and modeling could be joined together in the research purpose. The design of the study would be reminiscent of the enjoyment found in the quantitative statistics, encountered for the first time in graduate school, that I labored to learn. Hence, I view the three precursors supporting the final research study to have been the important and the influential learning that took place when I, myself, was a graduate student – in my early fifties.

The need for this study is founded on the research accomplished in the past in the areas of science modeling, direct metacognitive instruction and the benefit of contextualizing metacognition into content skills. Science modeling and metacognition are topics with much research available to inform instruction, however, studies demonstrating integration of science content skills with metacognition are limited. This study sought to fill that gap by advancing understanding of contextualizing the development of metacognition within the specific content skill of modeling. The rationale for the study is founded on the need for research to example a pedagogical strategy fusing metacognition and modeling which in turn strengthens our understanding of cultivating metacognition and of developing the science skill of modeling. The purpose of the chapter at hand is to frame the topics of study and to introduce the focus of the research to study the interplay between metacognition and modeling in chemistry.

Background and Rationale

The goals of the more recent Georgia Standards of Excellence science standards embrace the procedural understanding of science produced through the Science and Engineering Practices (SEP), prescribed by the NRC (National Research Council, 2012), and promote the role of metacognition in learning (Dooley, 2017). The SEPs, key process skills highlighted in recent national guidance of science instruction, could be strengthened by well-developed skills in metacognition and, at the same time, carrying out the science practices could increase student development of metacognition. A study of metacognitive cultivation contextualized in the development of one of the SEPs, could prove to be impactful research for the community of science teachers in Georgia and beyond.

Science teachers are tasked with developing science practices in our students in an integrated fashion with our science content. “Developing and using models” is SEP #2 (National Research Council, 2012). This practice is embedded into the Georgia Standards of Excellence, GSE, science standards throughout the curriculum. Although the advantage of practicing chemistry modeling has been studied and endorsed (Cooper et al., 2017; Justi & van Driel, 2006; Leenars et al., 2013 Louca & Zacharia, 2012; Sujak & Daniel 2017; Swartz, et al., 2017), the practice of using and creating models is difficult for students (Khan, 2011). Additionally, recognition of the role of models and modeling is recent in science education so many science teachers are not equipped to teach skillfully from a modeling perspective (Justi & van Driel, 2006). Evidence in the literature supports a study on the acquisition of modeling skill since the literature tells us that chemistry teachers and chemistry students have problems with understanding the nature of models and modeling as a practice (Erduran & Mugaloglu, 2014; Khan, 2011; Windschitl et al., 2008). Carpenter et al. (2019) noted that modeling is one practice that teachers struggle to fully understand and implement despite the practice being primary in the work of science.

Although the research community has accomplished much work regarding the effect of modeling on conceptual understanding of chemistry, it has produced little research regarding the students' cognitive processes involved in learning via modeling (Louca & Zacharia, 2012). Research strongly indicates the need for metacognitive expertise to develop knowledge of science through inquiry methods of science (Hacker, 2009) such as those found in the SEPs. Evidence has shown that students with higher metacognitive capabilities show greater gains when learning via inquiry-based instruction methods, such as modeling, than do the students with lower metacognitive capabilities (Hacker, 2009). This suggests that enhancing metacognition would lead towards augmenting the development of modeling skills.

Given that modeling is very challenging, introducing the practice to students during a modeling exercise produces metacognitive experiences, which refer to a student's awareness and feelings elicited in a problem-solving challenge. Development of metacognitive thinking processes, prompted by metacognitive experiences, have the potential to strengthen modeling practice and could be reflected in enhanced student mastery of the conceptual content served by the modeling. The success of intertwining metacognitive instruction with modeling will serve to help teachers and students alike for whom modeling practice is initially a challenge (Carpenter et al., 2019).

The science practice of modeling could be strengthened by well-developed skills in metacognition and, at the same time, carrying out the modeling practice increases skills in metacognition. The pedagogical strategy of this study to offer direct guidance in metacognition in tandem with developing one of the SEP examined the effect of pairing modeling with metacognition; the combination was unique and offered gains for student success in chemistry. The process of creating a model, by drawing a particulate representation of a process or structure, was connected to conscious reflection in metacognition when direct guidance in metacognition was done in tandem with the modeling activity in chemistry. The science practice of modeling and metacognition held the promise to benefit each other in a reciprocal fashion and to contribute to the acquisition of learning.

Instruction in metacognitive skills has been demonstrated to provide a more student-centered environment in the chemistry classroom, to facilitate metacognitive processes and to promote self-efficacy in chemistry (Kirbulut, 2014). According to Schraw, et al., (2006) the critical role metacognition can serve in scientific inquiry has motivated scrutiny of the balance of time devoted to teaching concepts in science in the absence of metacognitive instruction. It was noted to be better to devote the time to developing procedural understandings of science. Procedural skills, such as science modeling in chemistry, are considered linked to metacognitive skills (Schraw et al., 2006). Some science educators propose increasing time for procedural learning because procedural competence, linked to metacognition, is a large allotment of the problem solving and critical thinking demanded in higher levels of science education (Schraw et al., 2006).

The topic of instruction in metacognition is vital to understanding the role of metacognitive thinking in learning. A key debate noted by Zohar and Barzilai (2013) is whether metacognition is domain-general or domain-specific. The domain-specific view of metacognition is supported by studies (Cook et al., 2013; Schraw, 1995; Veenman, 2013) where metacognition is contextualized within specific tasks, specific domains, and specific content areas. The direct instruction of metacognition delivered within a specific domain (i.e., science) and the matrix of a content-specific skill (i.e., science modeling) holds the promise of potent development of metacognitive practices in students.

Students who "gain a level of awareness above the subject matter" (Chick, 2013, p.1) expand learning strategies most effectively when metacognitive instruction is embedded into the content and the activities with which they are engaged (Chick, 2013). Direct instruction of metacognition and contextualizing metacognitive cultivation within the SEP of modeling is a novel application and a beneficial example of how to embed metacognitive practice within a specific content. Therefore, the research study explored metacognitive instruction embedded into an inquiry-based SEP utilized in chemistry instruction to gather understanding useful to the community of chemistry educators.

This research examined an explicit contextualization: that of direct metacognitive instruction and guidance applied to the demanding chemistry practice of modeling. The evidence documented through this research, to support integration of the metacognitive instruction of into a content-specific task, furthers the current understandings of how to cultivate metacognitive practices in our students.

The value of direct metacognitive instruction has been established in conjunction with a positive effect on achievement in chemistry (Cook & McGuire, 2013; Kingir & Aydemir, 2012; Rahman et al., 2010; Uopasai et al., 2018). Specific facets of chemistry acquisition, such as problem solving (Cooper & Sandi-Urena, 2009), self-efficacy (Kirbulet, 2014; Zubeyde, 2014), and concept learning (Thomas & Anderson, 2014; Thomas & McRobbie, 2013; Tanner, 2012) have each been explored in concurrence with metacognition. Likewise, the learning advantage of practicing chemistry modeling has been studied and endorsed (Cooper et al., 2017; Justi & van Driel, 2006; Leenars et al., 2013 Louca & Zacharia, 2012; Sujak & Daniel 2017; Swartz et al., 2017).

This research fills a gap in the existing research by integrating metacognitive instruction and chemistry modeling, two evidence-based instructional pedagogical strategies that have yet to be examined in tandem. This research is positioned to contribute unique findings about metacognition and modeling. It can strengthen appreciation for the reciprocal benefit of metacognitive instruction and content-specific contexts in science and, indeed, all content areas.

Definition of Terms

Scientific Inquiry

Scientific inquiry describes the approaches of problem-solving and the processes of scientists used in investigating and explaining natural phenomenon by diverse methods (Klar, 2000). Schawrtz et al. (2004) defines scientific inquiry as characteristics of the processes by which scientific knowledge is developed. Scientific knowledge and scientific theories are built through scientific inquiry. In establishing a working definition of scientific inquiry, various definitions found in the literature (Akuma & Callaghan, 2018; Chen et al., 2020; Cullen, 2015; Mupira & Ramnarain, 2017; White et al., 2009) were synthesized and tailored to the goals of this research. This process produced the following definition:

Scientific inquiry originates with a question, posed by teacher or student, wherein the answer is sought by collecting evidence to support the construction of an explanation. The explanation is communicated, undergoes critique and revision before becoming a refined, justifiable answer to the question.

The research purported to investigate the effect of an independent variable, a cognitive intervention, on dependent variables, content skill and concept acquisition, to answer the question of how contextualizing metacognitive cultivation could enhance the science practice of modeling and the learning of chemistry. Hence the research in its very design overarchingly corresponded to the definition of scientific inquiry. The definition of scientific inquiry supports the experience of the participants in the study since a content question was investigated by evidence observed in the phenomena and an explanation was constructed by students in the form of a model which was critiqued, revised and refined to answer the question.

Metacognition

Metacognition is cognition that goes beyond commonplace thinking (Rahman et al.,2010) and is often defined as “thinking about one’s thinking” (Cooper & Sandi-Urena, 2009) since the term was first coined by John Flavell in the 1970s (Kinger & Ayedmir, 2012). Schraw and Dennison (1994) included both knowledge of cognition and regulation of cognition within the definition of metacognition. Yen et al. (2018) described metacognitive knowledge, metacognitive skills, and metacognitive experiences as a part of self-regulated learning. MK is the declarative knowledge about the interplay between person, task and strategy (Veenman, 2006). For example, a student knowing that memorization of element symbols is an easy task for her but that learning to work chemistry problems will take more work is MK. MS is the conscious and purposeful application of strategies and regulation of thinking to achieve desired outcomes. Examples of MS include a chemistry student taking careful notes on problem examples and referencing those notes as he works on the homework problems or a student making flashcards to memorize element symbols. It includes regulation, for example, a student checking a posted key, after completing homework, to correct errors. ME are the feelings or judgement experienced by the learner when a new learning challenge is presented. ME can also serves as feedback to aid in regulation of MS (Yen et al., 2018).

The definition of metacognition that was used in this study, offered by Thomas and McRobbie (2013), is an *"individuals' knowledge, control and awareness of cognition"* (p. 302) representing MK, MS and ME.

Models and Modeling

Models in chemistry education are diagrams or drawings which represent a view of a system, a phenomenon or process. Models often represent the sub-microscopic or the particulate level of Johnstone's triangle in chemistry (Thomas & McRobbie, 2013). Modeling is the work of a student to create a labeled or keyed drawing which represents the unseen elements present in a system, process or phenomena (Cooper et al., 2017). Students engaged in modeling observe or reflect on a macro process or event and interpret unseen processes and activity. The procedure involved in this research study replicated model-based inquiry as the basis for answering a specific conceptual question with an explanation (Louca & Zacharia, 2011). Synthesizing and refining a definition for models and for modeling based on the literature (Cooper et al., 2017; Louca & Zacharia, 2011; Santos & Arroio, 2016; Thomas & McRobbie, 2013). and tailored to the goals of the research accorded the following definitions:

Models in science explain and predict through representation something in the natural world; models show how an observed phenomenon works.

Modeling is the construction and revision of a representation to communicate the characteristics and/or relationships between components of a system with explanatory and predictive capability.

The use of a model to represent and communicate internalized understandings reflects the collaborative nature of science discovery in the work of scientists. The protocol of refining a model equally reflects the journey of science to refine knowledge of the universe through critique, testing and revision. Scientists communicate, collaborate and refine explanations to deepen and validate the understandings we hold about our world. Modeling, therefore, is a microcosm mirroring the mission of scientific inquiry.

Phenomenon

Phenomenon in chemistry instruction is an observable event ideally interesting, complex and aligned to the standard under study ("The Wonder of Science", n.d.). It can be demonstration of a physical process or a chemical reaction conducted as a demonstration. It can take the form of a video or a simulation showing the same also. Talanquer (2018) explained how students need to be able to investigate and make sense of macroscopic phenomena, tangible and visible events, to interpret chemical systems and to make arguments regarding causes.

Purpose of Study

The purpose of this research was to examine the interplay between science modeling and direct instruction in metacognition. The quasi-experimental study was designed to investigate how students' skill in science modeling was affected by the fortification of increased metacognitive skill and how each strategy, science modeling and metacognition, augmented the acquisition of chemistry content. Further, perceptions of metacognitive value and of metacognitive thinking processes were appraised in conjunction with the fortification of metacognitive skill. The research questions considered aspects of integrating metacognition instruction into the context of content skills for the novel application of metacognitive assimilation into the specific SEP of modeling.

The following research questions guided this study:

1. Does direct coaching or instruction of metacognition enhance modeling and the acquisition of the conceptual content?
2. Does direct coaching or instruction of metacognition enhance student awareness of metacognitive thinking processes?
3. Is there a correlation between student perception of the value of metacognitive activities and their awareness of metacognitive thinking processes?

Scope and Limitations

The research was conducted in the honors chemistry courses led by the researcher. Thus, it was considered quasi-experimental research. The risk of backyard research includes the study not being viewed as seriously by others. The process of the research was thoroughly scrupulous and data analysis handled with meticulous detail to garner respect of fellow educators.

Participants in the study were students in the honors level chemistry course and thus it is convenience sampling. The school is a large suburban high school located outside of a large metropolitan area in the Southeast where the majority of the students are from affluent families with high SES.

Significance of the Study

Improving teaching and learning from evidence-based findings is the goal of researchers in chemistry education (Towns, 2013). The robust benefit of designing an activity to serve modeling, metacognition and conceptual learning was exciting and useful to improve chemistry education. Contextualizing metacognition into content-specific skills added another layer of significance embedded in this study.

The significance of research in chemistry education should be evaluated on criteria including novelty, the impact and the influence of the findings (Towns, 2013). Investigating a research question that possessed novelty, had potential for impact and to exert influence in the field of chemistry education seemed daunting, yet this study built on the interplay between modeling and direct metacognitive instruction could benefit the field of chemistry education and could exert a far-reaching effect on the teaching practices of many chemistry teachers.

Chapter Two: Literature Review

Constructivism in Science Instruction

The perspective on learning undergirding this study emanates from model-based inquiry instruction which is grounded in the constructivist tradition (Louca & Zacharia, 2012). Scientific inquiry engages students in an authentic learning process to discover the workings of the natural world (Fox & Risconscente, 2008; Uopasai et al, 2018). Students can construct and internalize real meaning through their own investigations and build an experience-based understanding of why we believe what we believe about science (White et al, 2009).

Constructivism and Modeling

As described by Uopasai et al., (2018), the constructivist philosophy of science teaching and learning is centered on student mental models and their misconceptions. This possesses important implications for teachers who aspire to demonstrate scientific reasoning for their students. The teaching model, based on constructivism, draws on learning theories pioneered by Piaget, Vygotsky and James (Fox & Risconscente, 2008; Uopasai et al., 2018). Specifically, the model emphasizes the critical need to establish a cognitive framework and use relevant information to propel conceptual change.

According to Thomas and McRobbie (2013), student reasoning in chemistry should take place though conscious consideration of chemical phenomena at the macroscopic, the molecular/sub-micro and the symbolic levels and should generate construction, or revision, of the learners’ conceptual beliefs based on evidence. Within scientific inquiry, as evidence leads toward an explanation, the explanation can be communicated, critiqued and revised via the evaluation of models or within the practice of modeling to refine the answer to a scientific question and to strengthen the justification of the answer proposed (Louca & Zacharia, 2012). The scientific practice of modeling unequivocally undergirds and enhances the progression from the unknown to the known in the process of scientific inquiry.

Constructivism and Metacognition

Conscious, learner-regulated construction is at the heart of cognitive development (Glaser, 1984) and involves awareness of thinking and learning, which are key elements in metacognition (Thomas & McRobbie, 2013). The metacognitive approach of students using prior knowledge to plan a strategy, implement it, reflect upon it, evaluate the results and modify the approach plays a critical role in successful (Uopoasai et al., 2018).

Conceptual Framework

Support in the literature for the current study was provided within the conceptual framework. Specifically, the conceptual framework laid out three pillars of scientific inquiry: an understanding of models and modeling in science, the importance of metacognitive skills in chemistry learning and the benefit of direct instruction in metacognition contextualized into content skill for student success.

Scientific Inquiry in Science Education

Historical Evolution of Scientific Inquiry. Scientific inquiry, at its first enumeration in education, was proposed in contrast to the view of science before 1909, when science was understood to be a body of knowledge to be learned through direct instruction (National Research Council, 2000). In 1909, John Dewey argued for a change to the instruction of science to include the process or methods of scientists (Dewey, 1910). Dewey's model defined six steps:

sensing perplexing situations, clarifying the problem, formulating a tentative hypothesis, testing the hypothesis, revising with rigorous steps and acting on a solution (Barrow, 2006).

Science instruction gained national focus after the 1957 launch of Sputnik I. In 1960, Joseph Schwab encouraged science teachers to teach in a manner like science operates (Barrow, 2006). Schwab emphasized integrating scientific inquiry into science instruction by looking to the laboratory and using those experiences to lead instruction rather than as exercises to follow instruction (National Research Council, 2000). Schwab developed four variations of scientific inquiry in the classroom where the role of the student becomes increasingly independent: (1). questions are posed by the teacher and methods are provided to determine answers, (2). questions are posed by teacher and methods are open for students to determine, (3). students determine questions and methods and propose explanation based on experimentation, and (4). students conduct ‘enquiry into enquiry’ by using published experiments to establish explanations (National Research Council, 2000). By the 1970s, there were growing expectations that scientific inquiry should be a part of teaching science so that students would become involved in doing science rather than only being told about or reading about science (National Research Council, 2000).

The National Science Education Standards (NSES), a landmark public policy document, was issued in 1996 and expanded the idea of scientific inquiry in the classroom to include learners using inquiry steps and knowing the steps of conducting scientific inquiry (Barrows, 2006). This was followed by the publication of *Inquiry and the National Science Standards*, which identified five essential features of inquiry as follows: (a) scientifically oriented questions, (b) evidence collected by students, (c) explanations developed by students, (d) evaluation of their explanations (e) communication and justification of their explanations (National Academies of

Sciences Engineering and Medicine, 2000). Unpacking the NSES to address inquiry, three domains of inquiry in education were described to include the abilities to develop in students, the understanding of the scientific method students should know, and teaching standards for the inclusion of scientific inquiry.

Current Understanding of Inquiry. The original pedagogical term, inquiry, has evolved into “inquiry-based learning” (Heindl, 2019), which refers to the infusion of scientific inquiry into the classroom. This approach is now seen as essential for gaining scientific knowledge in the classroom as it has always been in pursuit of scientific knowledge among scientists. Inquiry-based learning departs from traditional learning because the teacher is not the center of the process. Thus, students are engaged in inductive discovery as opposed to being led in recipe science (Heindl, 2019). Inquiry strategies change the focus of instruction from learning what we know about science to learning why we believe what we believe about science. Thus, students gain understanding based on experience (Cullen, 2015).

Chen et al. (2020) note that existing literature offers different viewpoints about the fundamentals of scientific inquiry in the classroom. The essential abilities or competencies based on a synthesis of the literature on scientific inquiry are questioning, predicting, investigating, interpreting data, explaining, and communicating (Chen et al., 2020). Akuma and Callaghan (2018) describe inquiry-based learning as a reflection of scientific inquiry consistent with the social constructivist learning perspective which emphasizes knowledge being actively constructed by the learner. Mupira and Ramnarain (2017) concur that inquiry-based learning is constructivist, inductive and active learning characterized by questioning, data-analysis and critical thinking to construct real meaning and knowledge. Inquiry-based learning is meant to engage learners in an authentic discovery process (Pedaste et al., 2015, as cited by Mupira & Ramnarain, 2017).

Scientific inquiry has been viewed as a process of oscillating between theory and evidence within the practice of competitive argumentation (White et al., 2009). Scientific inquiry leads toward the development of scientific laws, models and theories by proposing theories then seeking evidence through investigation (White et al., 2009). From this perspective, the basic model of scientific inquiry is described as: (a) theorizing, (b) questioning and hypothesizing, (c) investigating and (d) analyzing and synthesizing (White et al., 2009).

Science Practices. More recently, there is a new emphasis driven by the K-12 Framework for Science Education (National Research Council, 2012) on mirroring the scientific practices of scientists and to illustrate the nature of science by shifting from the terminology of inquiry-based teaching methods to the assimilation of authentic scientific practices (French & Burrows, 2018). Authentic Scientific Inquiry (ASI) is defined as a fuller version of inquiry teaching that aligns more closely with the work of real scientists in contrast with traditional classroom labs (French & Burrows, 2018). NRC, in the 2012 public policy publication for U.S. national science standards, defined the scientific process as “practices” designed to engage students in authentic scientific inquiry and define the ways scientists gain knowledge (Donohue et al., 2020).

The practices, formally entitled Science and Engineering Practices, consist of the following: (a) Asking Questions and Defining problems, (b) Developing and Using Models, (c) Planning and Carrying Out Investigations, (d) Analyzing and Interpreting, Data (e) Using Mathematics and Computational Thinking, (f) Constructing Explanations and Designing Solutions, and (g) Engaging in Argument from Evidence (National Research Council, 2012). The

SEPs can be implemented with tiered strategies reflecting different levels of inquiry-based instruction. The SEPs may be integrated using traditional methods (i.e., question given→method given→answer given). However, the integration of the SEPs with the three highest inquiry levels, described by Schwab (1962) as "question open→method open→answers open", affords the greatest inclusion of the SEPs (Akuma & Callaghan, 2018). Therefore, open inquiry-based strategies align most with accomplishing the SEPs and affiliate strongly with scientific inquiry of science in the most authentic manner (Akuma & Callaghan, 2018).

Models and Modeling

Models as Metaphors. Models in science are explained by Schwartz and White (2005) as a set of representations, rules and reasoning structures that allow for the generation of prediction and explanation. Models can be considered extended metaphors that serve to apply information and understanding from the source domain, that of our common experience, to the target domain, the typically abstract and new concept we seek to master (Brown, 2003). Models as extended metaphors can guide thinking about a science system under investigation, however, they can also inhibit thinking about the system in other ways. According to Brown (2003), the role metaphor and modeling can play in successful science education is highlighted as it complements the sister goals of imparting conceptual understanding and generating a sense of intellectual excitement about the subject. These tools can correct embodied ideas that students bring with them and develop scientific reasoning. One of the pillars in explaining the construction of a metaphor include grounding it in common experiences with the physical world and understandings from the social domain (Brown, 2003).

Model Construction. Model-based learning in science occurs via student construction of models that represent physical phenomenon and externalize the underlying mechanism of an unseen process (Louca & Zacharia, 2012). Modeling is the process of building, using and evaluating external representations of systems to make sense of phenomena (Swartz et al., 2017). In the science classroom, viewing physical phenomenon and participating in group discussion pave the way for fruitful student - modeling (Leenaars et al., 2011). Gray and Rogan-Klyve (2018) summarized modeling as a reasoning practice used to anchor the "complex work of understanding and implementing scientific practices in the classroom to explain phenomenon and solve problems" (p. 1346). According to the NGSS (NRC, 2012) "Models serve the purpose of being a tool for thinking with, making predictions and making sense of experience" (p. 56). For scientists, models represent current understandings, help identify questions and explanations and are a means of communication. For that reason, "Developing and Using Models" is one of the SEPs recommended in the K-12 Framework for Science Education (National Research Council, 2012). Models include the following: diagrams, physical replicas, mathematical representations, analogies, and computer simulations (NRC, 2012).

Models are considered not merely representations of science processes and facts but are "tools for reasoning" (Swartz et al., 2017, p. 114). A modeling approach in science education is undergirded by constructivist learning theory (Leenaars et al., 2011). Leenaars et al. (2011) describe modeling construction as following the construction of internal mental models and manifesting perceptions. When the learner constructs an external model, it makes it concrete and moves it into the social dimension of science. Cooper et al. (2017) concluded, based on their research, that sketching to construct a science model is shown to be vital for revealing the quality of the student's mental models of a chemical process.

Models in Chemistry. The importance of models in the construction of chemical knowledge is suggested by philosophy of chemistry according to Erduran and Mugaloglu (2014).

Visual models are a dominant way of thinking in the subject of chemistry (Akaygun & Jones, 2014). The use of modeling is considered vital in explaining the relationships between the macroscopic (what can be seen) and the microscopic/particulate levels (Santos & Arroio, 2016).

Representational Levels in Chemistry. Learning chemistry with understanding involves a conscious inter-relating of three representations of chemistry: the macroscopic (what can be observed), the molecular/microscopic (what is happening on the unseen level), and symbolic (the abstract, written communication, such as an equation) as described by Talanquer (2011). The chemistry 'triplet' of representation was first proposed by Johnstone (1993). The emergence of a recognition and enumeration of three components of chemistry in common use provided the chemistry instructors a manageable paradigm to use (Talanquer, 2011).

Models and Representational Levels. Proficiency in the use of these multiple representations, macroscopic, submicroscopic and symbolic, in chemistry has been demonstrated to show improved understanding for grade nine students when studying chemical reactions and that the submicroscopic, in particular, must be described with models although it is the most difficult to nurture (Chandrasegaran et al., 2011). Within the submicroscopic representational level, the science practice of particulate modeling is utilized as an explanatory means of showing that representational level. Particulate modeling exhibits understanding and facilitates a bridge between macroscopic phenomenon and submicroscopic representation (Santos & Arroio, 2016).

Metacognition and Representational Levels. Louca and Zacharia (2012) note that making the connections between the three representations emphasizes metacognition because the process engages students to consider how they think about chemistry. Thomas and Anderson (2012) have presented similar findings on the role of metacognitive awareness in enhancing students' ability to move from one representation of chemistry to another.

Learning Through Model Construction. Learning through modeling, as described by Louca and Zacharia (2012), emerges from the interaction of the learners' experiences and ideas which are communicated and solidified through construction of an artifact, a concrete model. This process, called constructive modeling (Kokkonen, 2017), is often embedded in an inquiry activity wherein a model is constructed to generate a hypothesis about a question or problem regarding a phenomenon. Constructed models are developed, tested and revised within the inquiry activity. Cooper et al. (2017) defined modeling as "sketching the invisible to predict the visible," which develops model-based reasoning and is an important means of assessing understanding in the chemistry classroom (p. 902). Since modeling is considered a skill critical to developing the molecular/microscopic conceptual understanding (Louca & Zacharia, 2012), it is a vital tool.

Model Construction and Misconceptions. Sujak and Daniel (2017) contended that the non-emphasis of chemistry teachers on the molecular/microscopic level leads to misconceptions. Modeling can promote accurate understanding and help identify misconceptions (Santos & Arroio, 2016). Furthermore, Cooper et al. (2017) found that students who drew more models showed the greatest learning gains and these drawn models were invaluable as assessment tools for revealing students' misconceptions.

Model Construction and Increased Content Acquisition. When Kimberlin and Yezierski (2016) studied the effect of high school students engaged in using particulate level modeling in stoichiometry, they found the intervention significantly improved conceptual understanding of stoichiometry. Moreover, they found anecdotal evidence of gains in algorithmic understanding of stoichiometry. Similarly, Okumus et al (2019) found that the combination of cooperative learning and creation of models increased conceptual understanding about chemical reactions in a general chemistry course populated by pre-service science teachers. In a study conducted by Edwards and Head (2016), when modeling was paired with inquiry in an activity introducing the vocabulary of the representational levels in chemistry, students showed gains in understanding and application of the vocabulary.

Metacognition

Metacognition, a term originating from the work of John Flavell (1979) and Ann Brown (1987), describes one's knowledge about and regulation of one's cognitive abilities in learning processes. Metacognition has been catch-phrased as 'thinking about thinking" (Chick, 2013). The researchers Schraw et al. (2006) align metacognition alongside cognition and motivation as equal components of learning.

Metacognitive Theory. Metacognition is considered a facet of cognitive learning theory and an application of social-cognitive learning theory, For the psychologist James, metacognition was an activity of the self. He paralleled awareness of one's own cognition with maturing into adulthood when such thinking was thought to become habitual (Fox & Riconscente, 2008). Piaget defined metacognition as conscious awareness and the ability to communicate rationale for one's thinking (Fox & Riconscente, 2008). Vygotsky's work expanded the definition of metacognition to include not only awareness of cognitive activity of the mind but also control and direction of thoughts by use of signs. Vygotsky also described the knowledge of one's mental powers in relation to a given task as another key facet of metacognition (Fox & Riconscente, 2008). According to Vygotsky, metacognition is enhanced by scientific concepts and promoted through social interaction with others, including adults. The use of language, via social interaction, and the acquisition of scientific concepts promote MK and propels the child toward a mature ability to grasp and formulate concepts, and to transfer new understandings to novel situations (Fox & Riconscente, 2008).

Components of Metacognition. Metacognition can be divided into two broad, distinctive and independent components: a) knowledge of cognition and b) metacognitive regulation (Schraw et al., 2006; Deng et al., 2011). Metacognition has also been defined as three aspects of a cognitive process: knowledge of the process, monitoring of the process and control of the process (Hacker, 2009). Bowen et al. (2017) agree that metacognition is not only knowledge of how one learns or thinks but also has a regulatory aspect involving planning, monitoring and evaluating. Planning, monitoring and evaluating are prescribed steps to consolidate the skill of understanding and monitoring one's learning or cognitive processes (Bowen et al., 2017). Regulation of cognition is applied to the exact task and thus includes "planning for, monitoring the progress of and evaluating projects or investigations" (Hacker, 2009, p.180).

Definitions of Metacognition. After the inception of the term metacognition by Flavell (1979), many different "flavors" of definitions were proposed, some of which are redundant and others conflicting (Zohar & David, 2009). Veenman et al. (2006) noted the domain of metacognition lacks coherence and has inconsistency in its concepts although its importance is agreed upon. The literature suggests, as noted in examples above, that the definition of metacognition is usually three parts with synonymous although non-identical components. The three components articulated by Tobias and Everson (2002) seem to represent this accepted structure wherein metacognition can be broken down into knowledge about metacognition, ability to monitor the learning process and the meta-ability to control the learning process.

Scholars (Thomas & McRobbie, 2013; Yen et al., 2018) have divided metacognition into three facets: metacognitive knowledge (MK), metacognitive skills (MS) and metacognitive experiences (ME). Thomas and McRobbie (2013) define metacognition as “individuals’ knowledge, control and awareness of cognition” (p. 302) representing MK, MS and ME. MK is declarative knowledge about the interplay between person, task and strategy (Veenman, 2006); MS is the conscious and purposeful application of strategies and regulation of thinking to achieve desired outcomes and ME is the feeling or judgement experienced by the learner which also serves as feedback to aid in regulation of MS (Yen et al., 2018).

More recently, Graham et al. (2019) detail the three facets of metacognition:

> (1) Metacognitive knowledge/awareness: an individual’s knowledge of what they know and/or beliefs about their own self, knowledge of the task, goals, and knowledge of various effective strategies. (2) Metacognitive skills/strategies: the ability to think about what you are currently doing and then select and utilize appropriate learning strategies such as planning, self-monitoring, self-evaluation, self-regulation, orienting, and more. They reflect the skill with which an individual can monitor, guide, and regulate their own thinking and learning. (3) Metacognitive experiences: the affective (emotional) or cognitive experiences that occur during metacognition (p. 1539).

Under metacognitive knowledge/awareness falls the components of metacognitive knowledge (declarative) and metamemory. Under metacognitive skills/strategies falls metacognitive knowledge(conditional) and metacognitive skills. The third facet is metacognitive experiences. It is also noteworthy that metacognitive beliefs affect declarative knowledge, procedural knowledge and metacognitive experiences (Graham et al., 2019.)

Metacognitive Declarative Knowledge. Distinct facets or components of metacognition have each been highlighted in the literature. A common distinction in metacognition that appears in the literature separates MK or declarative knowledge from MS or procedural knowledge (Schraw, 1988; Thomas & McRobbie, 2001; Veenman et al., 2006). Declarative knowledge is one's beliefs about the tasks, conceptions about one's abilities and encompasses one's goals; while procedural knowledge (part of MS) refers to knowledge about how one performs cognitive tasks or how one regulates problem-solving.

Metamemory, which is associated with developing declarative knowledge (Veenman et al., 2006), is often studied in younger children and is concerned with the knowledge and control of one's memory (Karably & Zabrucky, 2009). It contains two components: stable knowledge (i.e., how one learns including understanding of the person, task and strategy of learning), and procedural metamemory, which emanates from meta-experiences where memory becomes instrumental in recalling how to use strategies and in evaluating progress (Karably & Zabrucky, 2009).

Metacognitive Skills. MS entail procedural knowledge, conditional knowledge and meta-strategic knowledge (MSK). The components described in metacognition as conditional metacognitive knowledge recognize the value and the limitations of procedural knowledge (Thomas & McRobbie, 2001) and are about knowing "what to do when" (Veenman et al., 2006, p. 5). Declarative and procedural knowledge can serve to equip students, but it is the conditional knowledge that appropriately applies the two making metacognition effective. All three interact in the function of metacognition (Thomas & McRobbie, 2001) although the interaction of the three is not yet clearly defined (Zohar & David, 2008). Specifically, in the context of science inquiry, White and Frederiksen (2005) defined MK and MS in three parts as: (a) knowledge about capabilities and goal structures needed in science inquiry, (b) knowledge of how one organizes and manages science inquiry processes and (c) knowledge of how to apply one's metacognitive capabilities in science inquiry.

MS have been spotlighted as advantageous for all learners in the literature. Veenman et al. (2006) demonstrated that metacognitive skills, uniquely account for 17% of variance in learning, intellectual ability accounts for 10% of variance in learning and the two together share another 20% of variance in learning for students of different ages and background, for different types of tasks, and for different domains. The implication is that proficiency in metacognition may compensate for students' cognitive limitations (Veenman et al., 2006). White and Frederiksen (2005) report findings of responses from students, who participated in metacognitive development through computer-guided activities, which indicated that students saw their capabilities as subject to reflection and improvement. A significant decrease in the performance gap between high-achieving and low-achieving students was linked to the metacognitive approach by the researchers thus encouraging the "important idea that anyone can learn and improve" (White & Frederiksen, 2005, p. 222).

Metastrategic knowledge, MSK, is a term linked to procedural and conditional knowledge of metacognition (Kuhn, 2001; Zohar & David, 2008). MSK is defined as general knowledge about higher order thinking strategies (Zohar & David, 2009) that involves understanding a thinking strategy and knowing when it should be used along with being able to outline the strategy. MSK also incorporates an understanding of the task as part of meta-strategic thinking (Kuhn, 2001; Zohar & David, 2008).

Metacognitive Experiences. ME are believed to be critical to the development of metacognitive knowledge by becoming the basis for metacognitive reflection (Thomas &

McRobbie, 2013). ME are experiences related to cognitive endeavors or to behaviors or to metacognitive knowledge which elicit monitoring of cognitive process or outcomes (Thomas & McRobbie, 2013). Experiences are the feelings and the judgements taking place during metacognition (Graham et al., 2019). ME are most powerful when contextualized within appropriate content-rich activities (Crick, 2013; Thomas & McRobbie, 2013). These experiences create an opportunity for students to reflect and revise as they are prompted to think about how they learn in relation to the content area and to evaluate the consequences of changing learning processes (Thomas & McRobbie, 2013). ME produce feedback to behavioral control processes as students monitor and assess outcomes thus allowing for deficiencies to be corrected (Graham et al., 2019).

Metacognitive Beliefs. Metacognitive beliefs describe beliefs held about one's thinking (Flavell, 1979) and are considered to have a place in self-regulation and in judgements made in ME (Nelson et al., 1999). Metacognitive beliefs act as a declarative knowledge about the self and will prompt action to self-regulate when an individual desires a state different than the one they are in presently (Nelson et al., 1999). Positive metacognitive beliefs relate to the perceived potential of 'thinking' to benefit an outcome. It is noted that even test anxiety can be considered positive metacognitive belief because the individual thinks that worrying about a test will help them be more successful on the test. Negative metacognitive beliefs are based on believing that there is danger in 'thinking'. An individual, for example, may believe that thinking about bad things could cause bad things to happen (Fergus et al., 2020).

In summary, metacognition is both about oneself and about the current, precise mission of learning being undertaken. The metacognitive approach of students (using prior knowledge to plan a strategy, implement it, reflect on and evaluate the results, and modify the approach as called for) plays a critical role in successful science learning (Uopoasai et al., 2018). Regulation of cognition goes hand-in-hand with procedural understanding of science which can be learned through inquiry and the science practices (Hacker, 2009). Investigation into their own metacognitive practices is a path to enable students to learn about scientific theorizing and inquiry while also increasing their metacognitive growth (Hacker, 2009).

Metacognition in Science Instruction

The literature reveals manifold approaches to investigating metacognition in science and in chemistry education specifically. The value of embedded metacognitive instruction has been established in conjunction with a positive effect on achievement in chemistry (Deng et al., 2011; Thomas & Anderson, 2014; Thomas & McRobbie, 2001; Uopasai et al., 2018). Deliberate instruction in metacognitive strategies in the science classroom appears to enhance both metacognition and learning in a broad range of students (Cook &McGuire, 2013; Graham et al., 2019; Seraphin et al., 2012; Zepeda et al., 2015). Use of interventions to produce metacognitive experiences have been explored in chemistry instruction (Casselman & Atwood, 2017; Cooper & Sandi-Urena, 2009; Thomas & McRobbie, 2013) and metacognitive awareness has been examined for relationships to chemistry student efficacy and achievement (Kingir & Aydemir, 2012; Kirbulet, 2014; Rahman et al., 2010).

Direct Instruction in Metacognition. Direct, purposeful instruction and specific guidance about metacognition and metacognitive strategies have been examined in the research literature and specifically in science education. Three fundamental principles described by Veenman et al. (2006) for successful metacognitive instruction involve: (a) embedding metacognitive instruction in the content to ensure connectivity, (b) informing learners about the usefulness of metacognitive activities to encourage the initial extra effort, and (c) prolonged training.

Approaching instruction through constructivist practices featuring integrated metacognitive guidance has proven beneficial. Uopasai et al. (2018), for instance, found a significant difference in overall academic outcomes between experimental and control groups of veterinary medicine students when the experimental group was subject to a teaching intervention based on constructivism, metacognition and neurocognition as compared with traditional teaching methods in the control group. The teaching method was credited with enhancing students' abilities in understanding medical terminology and anatomical knowledge, and with increasing metacognitive ability, including declarative, procedural and conditional knowledge (Uopasai et al., 2018). Similarly, Deng et al. (2011) compared content acquisition and metacognition in eleventh grade chemistry students in China. When the treatment group was given a constructivist data-logging activity (as opposed to the traditional teacher-centered methods used in the control group), both metacognition and conceptual understanding increased.

Studies have illustrated how deliberate use of language that emphasizes and guides metacognition in the chemistry classroom improves student outcomes as well. For example, Thomas and McRobbie (2011) found that embedding a constructivist metaphor "learning is constructing" into the daily work of Australian chemistry students generated variable effects on student metacognition. The case study, featuring a catalytic ME, showed some gains in MK specifically (Thomas & McRobbie, 2001). More recently, Thomas and Anderson (2014) confirmed that changing the learning environment of a chemistry classroom through the use of language that explicitly addresses metacognition and uses metaphor to guide how students think about the three representational levels of chemistry can lead to changes in students' metacognitive knowledge. The Metacognitive Orientation Learning Environment Scale- Science (MOLES-S; Thomas, 2003) was used alongside the Self-Efficacy, Metacognition Learning Inventory- Science (SEMLI-S; Thomas et al., 2008) with additional support of student interviews (Thomas and Anderson, 2014). The study highlights the idea that students' metacognition should be developed and enhanced through teaching activities which embed training in metacognition into science learning (Thomas & Anderson, 2014).

Short Term Instruction. Short exposure to direct instruction of MS or metacognitive strategies is also supported in the literature as having an impact on academic performance, the growth of student metacognition, the conceptual understanding of chemistry and self-efficacy beliefs of students toward chemistry. The following referenced studies support the methodology of short exposure to direct metacognitive instruction for significant gains in chemistry. Cook et al. (2013) found that through a mere 50 minutes of direct instruction about metacognition, college chemistry students without metacognitive learning strategies can be taught metacognitive strategies resulting in significant improvement in test scores in chemistry. Specifically, students in the study were instructed on MS and introduced to a study cycle eliciting ME. According to surveys and interview, attending a lecture on metacognition was shown to change student behavior resulting in a statistically significant improvement in test scores (Cook et al., 2013). In another study examining the effect of direct instruction on metacognition, Zepeda et al. (2015) implemented a six-hour intervention implemented designed to teach declarative and procedural metacognition. Science students performed significantly better on a conceptual test and a self-guided learning activity after exposure to the direct instruction on metacognition.

Longer Term Instruction. There have also been studies of longer-term interventions based on direct instruction of metacognition. Graham et al. (2019), for example, developed an approach for direct instruction of metacognition framed in weekly chemistry tutor sessions in college introductory chemistry courses. These sessions produced gains in self-efficacy in STEM and increased student achievement. Development of MK and MS were the focus of the twelve tutoring sessions followed by an opportunity to apply MK and MS directly to chemistry tasks therefore inducing ME (Graham et al., 2019). Seraphin et al. (2012) developed an instructional intervention that involved explicit teaching of metacognitive strategies and metacognitive reflection coupled with science inquiry, which they presented to teachers enrolled in professional development over two years' time. When the teachers implemented these practices with students, they were shown to increase science processing skills and metacognition in both teachers and students. These examples demonstrate effects of long-term instruction in metacognition for science and chemistry education.

Instruction Based on ME in the Chemistry Classroom. Metacognitive guidance in conjunction with an inquiry activity produces a learning environment rich in ME in which students can develop metacognition and self-efficacy in chemistry (Kirbulut, 2014). Researchers who develop an intervention to draw out ME, have seen gains in metacognition and achievement in chemistry. Based on interviews with students conducted after the students participated in an inquiry activity, Bowen et al. (2017) found that the students credited the activity with prompting metacognition. Further, the students described intermediate or high-level MS in their actions during the activity. This research suggests that even students are cognizant of the interaction between metacognition and inquiry, as well as, the resulting benefits when they reflect on learning activities (Bowen et al., 2017). Casselman and Atwood (2017) stimulated ME by means of a treatment group experiencing direct metacognitive training in chemistry online homework exercises (i.e., where students predicted quiz scores, received the quiz feedback and followed up with self-designed weekly study plans to address the quiz results). The metacognitive intervention produced significant gains in test performance over the course of a semester with the lowest quartile of students seeing the greatest gains (Casselman & Atwood, 2017).

Sandi-Urena et al. (2011) promoted ME in chemistry classrooms via a collaborative intervention that simulated a cognitive imbalance experience to provoke metacognitive reflection and social interaction. An increase in use of MS, a significant increase in metacognitive awareness, as indicated by the Metacognitive Activities Inventory (MCAI; Cooper & Sandi-Urena, 2009), and an increase in problem-solving abilities in chemistry were all gains supported by the intervention (Sandi-Urena et al., 2011). Thomas and McRobbie (2013) utilized an interpretive methodology in a study with multiple data sources from a treatment group emanating from a teachers' pedagogical shift to an activity system to elicit ME and guided reflection for two years. Videos of class time and interviews provided data in interviews to validate the effect of a changed pedagogy to develop student metacognition (Thomas & McRobbie, 2013).

Student Awareness of Metacognitive Practices. Metacognitive awareness has been highlighted in the literature as a promising indicator for producing success in science performance. Rahman et al. (2010) investigated the role of metacognitive awareness in academic performance in chemistry and found significant correlation between students' metacognitive awareness and their performance on a researcher-made chemistry test. The study measured metacognitive awareness using an inventory, Schraw and Dennison's Metacognitive Awareness Inventory (MAI; 1994), and measured performance using a researcher-created test and subsequently conducted a correlational analysis (Rahman et al., 2010). The metacognitively aware students performed well on the test demonstrating that awareness of metacognition can hold a profound potential for improving performance in chemistry.

In addition, the findings of a study conducted by Kinger and Aydemir (2012) reveal a strong positive association between attitudes toward chemistry and metacognition awareness. The study compared the MAI (Schraw & Dennison, 1994), and Attitude Scale toward Chemistry in conjunction with student course averages to reveal significant correlations between the three. Additional information was obtained via a Student Background Questionnaire containing questions pertaining to topics such as parental education, resources (i.e., books, study desk) available at home and parental employment. The study noted the students possessed greater declarative knowledge than procedural knowledge in chemistry indicating room for further integration between procedural knowledge and metacognition (Kinger & Aydemir, 2012). These findings suggest that strengthening procedural knowledge is a desirable goal in a learning activity. In an investigation of the relationship between the self-efficacy of students and metacognitive awareness, Kirbulut (2014) found that highly efficacious students were more aware of their own knowledge, (i.e., MK), and regulation, (i.e., MS), of cognitive processes. Kirbulut's (2014) action research data suggests that specifically in the domain of chemistry, highly efficacious chemistry students were more aware of their metacognition.

Corresponding to the above studies, metacognitive awareness in chemistry education has been demonstrated to produce gains in chemistry learning. The strong recommendation based on the study of Rahman et al. (2010) is that metacognitive strategies be encouraged in students through instructional activities since significant impact on student performance was seen for students with higher metacognitive awareness.

Metacognition Observed in the Chemistry Classroom of the Researcher

Formative Observations

In the chemistry classroom, MK can be used and further developed as students encounter all aspects of chemistry learning. When students encounter quizzes and tests, they must draw upon MK about themselves, tasks and strategies. This is evidenced by the increase in capability on quizzes after the first few quizzes. The students acquire a know-how in approaching this new kind of math-integrated science and with representational forms previous unbeknownst to them. Consequently, the metacognitive declarative knowledge specific for the study of chemistry appears to grow. Conditional metacognitive knowledge of when to apply a strategy or an approach becomes important in assessments, daily work and lab work. The students coming in from biology, where the strategies for success are different, always seem to have an adjustment when they enter the chemistry classroom. For example, students know that daily work is only graded for completion and shown work, not accuracy. However, many students after they complete homework, go up to the front of the room to check their work against the handwritten key. By early in the semester, it is a minority of students that do not review the posted key and thus it seems most have recognized by conditional MK a new strategy to apply. Likewise, students develop strategies and procedures to ensure lab report success. They learn that all conclusions need actual data. MS is seemingly employed to recognize the task performance that will produce the desired outcome when a lab is scored and utilize the strategies needed. Quizzes are formative assessments that provide opportunities to grow in metacognitive thinking skills because they alert the student to areas of concern, affecting MK, and prompt a self-regulation, MS, before the test to adapt. Students develop and apply the strategies needed to become successful when they receive feedback and are made aware of not reaching a desired goal. Students seem to grow in metacognition through quizzes.

Summative Observations

A discussion of metamemory and metacognitive beliefs must include summative assessment behavior observed in the classroom. By year 10 and 11 of high school, students have much familiarity with how their individual memory works and what helps them to master a content area before a summative evaluation. Also, they have metacognitive beliefs about review, cramming, coming to WEB review, making flash cards, highlighting notes, or showing up as soon as possible to sit for a test. One sees diverse approaches to preparing for tests that are informed by their positive metacognitive beliefs about actions that will help them succeed. One also observes that there are some students who claim little to no preparation will help them indicating an established metacognitive belief relating to tests. For tests, students do not seem to have adapted strategies to the task at hand for the specific content but they usually comment on reliance on well-established methods founded on long held metacognitive beliefs.

Survey Instrument Chosen for Adaptation.

The instrument Metacognitive Activities Inventory, MCAI, (Cooper & Sandi-Urena, 2009), was chosen for adaptation by the researcher. MCAI was found to be a robust, reliable and validated assessment of metacognition in chemistry problem solving (Cooper & Sandi-Urena, 2009). The researchers described the findings in the validation study:

> Reliability was measured in terms of internal consistency, as well as the reproducibility observed after retesting. Validity was examined in two dimensions: face validity, in terms of the acceptability and reasonableness to those who are tested; and construct validity, in the extent to which its items conform to the functional definition of the construct measured and its ability to predict group differences. It is estimated that the evidence gathered sufficiently supports the validity of the inventory." (Cooper & Sandi-Urena, 2009, p. 244).

The MCAI was used in a study as a data collection method to assess and strengthen an approach to measuring metacognition in chemistry problem solving using multi-methods (Cooper et al., 2011). An additional study featuring an intervention of providing cooperative, project-based laboratory experiences to increase problem-solving ability and metacognitive strategies also utilized the MCAI (Cooper et al., 2012).

Theoretical Framework

Constructivism Undergirds Learning Chemistry through Modeling

Constructivist learning theory applied to the teaching of science is said by Colburn (2000) to involve the refining of student beliefs about science to become more in line with the beliefs held by the scientific community. He explains that science teaching from a constructivist perspective will guide students to understand "how and why scientifically accepted explanations explain and predict what will happen in a given situation better than their intuitive ideas" (p. 10). As knowledge is actively constructed in an inquiry method via the modeling of a chemistry phenomenon, misconceptions can be replaced with solid scientific ideas about how the world works. Research strongly indicates the need for metacognitive expertise to develop knowledge of science through inquiry methods (Hacker, 2009).

Metacognition and Modeling Interplay to Benefit the Learning of Chemistry

Metacognition is considered an application of social-cognitive learning theory and metacognition is a facet of cognitive theory. MK encompasses our specific knowledge of the content at hand or knowing "what you know and what you don't know" about the specific content to be mastered. MS and the regulation of cognition are applied to the exact task and thus includes "planning for, monitoring the progress of and evaluating projects or investigations"

(Hacker, 2009, p.180). Therefore, the student benefits from metacognition which is defined by Veenman (2011) as “knowing what one knows and does not know, from knowing oneself in the learning process, from reviewing and evaluating choices and evidence” (p. 213).

Planning, moderating and evaluating are requisite mechanisms for student metacognition (Bowen et al., 2017). The practice of modeling elicits active engagement from the student and produces a metacognitive experience. Guiding student reflection on the three processes of metacognitive practices in tandem with an activity of science modeling promotes skill in metacognition. Science practices are strengthened by developing skills in metacognition and, at the same time, carrying out the practices increases skills in metacognition. The SEPs and metacognition benefit each other in a reciprocal fashion.

The purpose of this research was to examine the interplay between science modeling and direct instruction in metacognition. The quasi-experimental study was implemented to investigate how high school chemistry students’ skill in science modeling could be bolstered by the fortification of increased metacognitive skill and if each strategy, science modeling and metacognition, could augment the acquisition of chemistry content. It investigated what impact integrating metacognitive instruction into modeling activities had on the acquisition of the chemistry content addressed by the model constructions. See the summary of the framework illustrated in Figure 1.

Research Questions

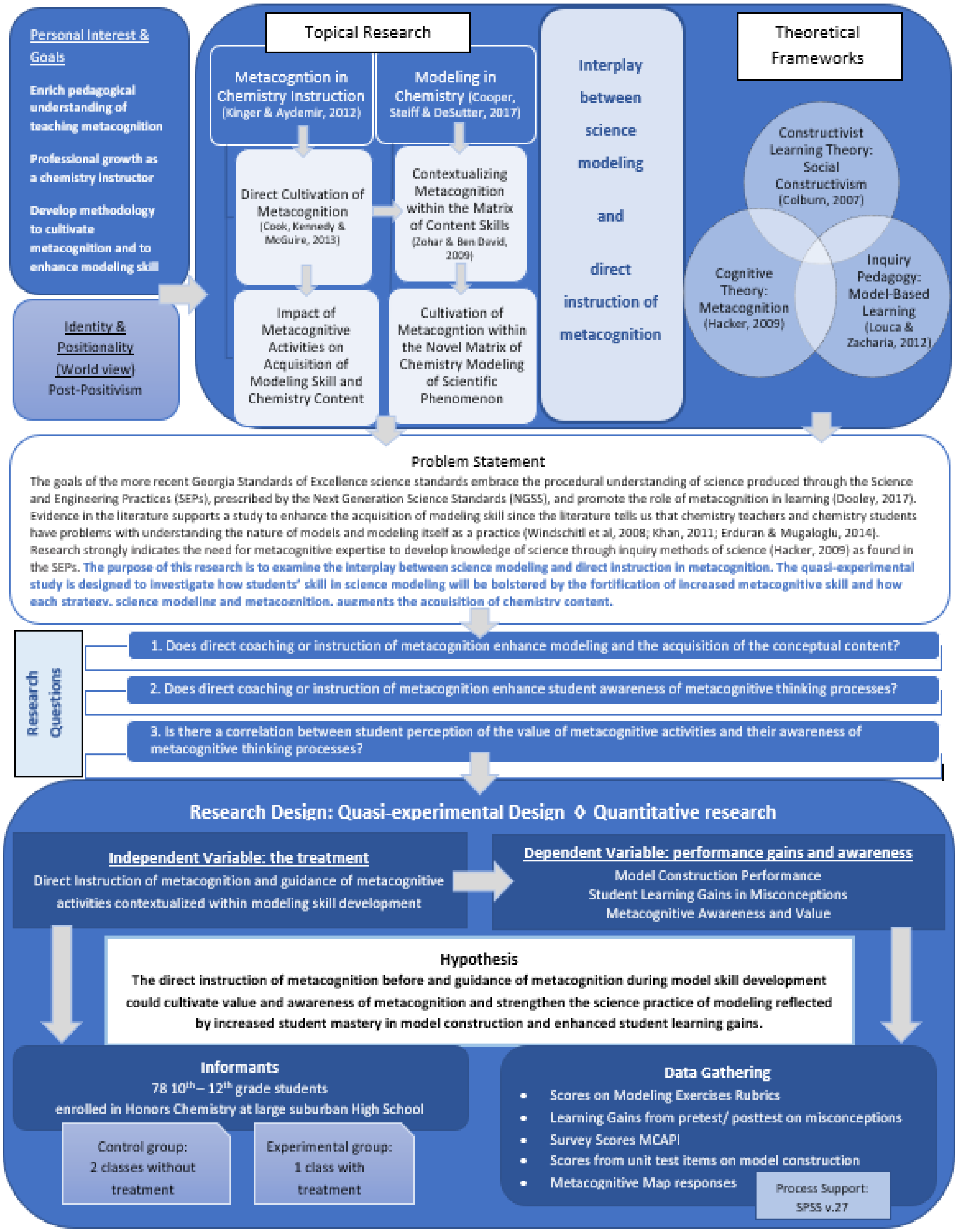
The following research questions guided this study:

1. Does direct coaching or instruction of metacognition enhance modeling and the acquisition of the conceptual content?

2. Does direct coaching or instruction of metacognition enhance student awareness of metacognitive thinking processes?

3. Is there a correlation between student perception of values of metacognitive activities and their awareness of metacognitive thinking processes?

Figure 1. Conceptual Framework: Metacognition and Modeling in Chemistry Instruction



Chapter Three: Methodology

Rationale for Design

The research method was conducted as a quasi-experimental design utilizing quantitative analysis; a quasi-experimental design seeks the nature of the relationship between an independent variable and a dependent variable. Quasi-experimental does not possess a true experimental design because the participants are not randomly assigned to the groups of control group and experimental group. The design methodology was appropriate to the natural setting of the classroom and was an effective means of demonstrating the effect of the intervention or independent variable, although, the methodology could expose threats to validity and limitation in generalizing the results. The choice of quasi-experimental design utilizing quantitative data and analysis is appropriate for the positionality of the researcher of post-positivism wherein cause and effect relationships can be observed to discover truth.

The present study was driven by the constructivist's theory of learning, based on the assumption that learners are active participants in the learning process, and thus metacognition could be cultivated through direct instruction. Therefore, the study involved integrating an intervention (i.e., direct instruction in metacognition) into chemistry content. The goal of the intervention was to enhance learning by applying direct instruction of metacognition to modeling. The investigation into possible correlational relationships between cultivation of metacognition, the science practice of modeling, and the possible influence on student performance in chemistry signaled the use of quantitative research methods. The effect of an intervention was best assessed through experimental or quasi-experimental design, which incorporates independent and dependent variables. Groups that are matched in characteristic (i.e., age, course level, content expectations, teacher) comprise fitting samples for the experimental and control groups.

The research design reflects the theory that metacognition integration into content is powerful. Cultivating metacognition is best, not as a stand-alone strategy, but when instruction of metacognition is immersed into a content skill; it is best embedded into the activities about which students are thinking (Chick, 2013). Zohar and David (2007) demonstrated teaching metacognition within a concrete learning experience is valuable because students use a thinking strategy within a context and are not merely learning metacognition in abstract. The placement of metacognition within development of modeling offered a theoretical confirmation of the work of Zohar and David (2007) who showed that metacognitive instruction is most impactful when contextualized within content.

Design

The study sought to understand if students perceived favorably the value of direct metacognitive instruction to enhance their science skills, and if the direct instruction of metacognition improved the science skill of modeling and student acquisition of the content.

In answering the first research question on the effect of direct coaching/ instruction of metacognition on modeling and the acquisition of conceptual content, the independent variable was whether or not students received the intervention (i.e., direct instruction on metacognition). Specifically, the independent variable was defined as a presentation on the concept of metacognition and use of a metacognitive guide for reflection during the introduction and subsequent practice of modeling. The dependent variables were measured with scores on the models produced and learning gains scores based on the scores of the pretest/posttest. To underscore the investigation of the effect of metacognitive guidance on the science practice of modeling, the course unit test items evaluating the model construction were also compared.

In answering the second research question on how direct coaching/instruction for metacognition affects students' awareness of metacognitive processes, the independent variable was whether or not students received the intervention (i.e., direct instruction on metacognition) and the dependent variable were scores on the survey instrument.

In answering the third research question on if there is a relationship between student perception of value of metacognition and students' awareness of metacognitive processes, the two variables were compared using scores on the survey instrument.

In summary, the dependent variables were defined as scores on models, learning gains scores from pretest/posttest and scores on models from the course unit test alongside the responses to student survey on metacognitive activities. The instructor, the age group, and the level of chemistry were controls since both experimental and control groups will share these same characteristics. The control variables, class of students and level of chemistry course, are defined as sophomores or 10th grade and honors level students, and the intervening variables, academic motivation and gender are defined as baseline test average and female/male.

Setting

The research was conducted in large suburban high school located outside of a major metropolitan area in the Southeast. It has been recognized nationally as a high-achieving school of excellence, ranked among the top 150 schools in the nation by *U.S. News and World Report*, and has been ranked consistently among the top five in the state (US News and world Report, 2020). The school demographics were described in 2020-2021 as 64% white, 20% Asian, 6% Black, 7% Hispanic, 3% multiracial and other (K-12 Public Schools Report Card, 2021). The gifted population was 44%, the graduation rate was 94.6% in 2021 and 4% of the student body is considered economically disadvantaged, meaning they are eligible for free or reduced lunch (K-12 Public Schools Report Card, 2021).

The student population has an overall characteristic of an unusual awareness of their academic progress and goals. The gifted population is 44% of the school community. School attendance is high, in part, due to a previous incentive policy. The data for the three years previous to the Covid-19 pandemic had attendance for all students at 66.1% for 5 or fewer absences; most of the 66.1% were absent only 2 days per semester (K-12 Public Schools Report Card, 2019). The incentive policy has been suspended for the current school year as a response to the Covid-19 pandemic. Students attended school either face-to-face or virtually during the same class period during the semester of the research.

Participants

Convenience sampling was used, specifically, all students from the honors chemistry classes currently instructed by the researcher were invited to participate in the study (n = 76). The ages of the sophomore students ranged from 15-16 years and the students were predominantly sophomores and juniors in high school. The student population in the chemistry courses was roughly the same as the school population. Students attended class during the same time period each day but attended either face-to-face or virtually.

Data was collected from those granted permission to participate by informed consent and student assent forms distributed prior to the lesson cycle (see APPENDIX A). As this is a quasi-experimental study, the sample was not randomly assigned to control and experimental groups but was assigned according to course section. Seventy-eight students were invited to participate in the study who were enrolled in three honors course sections. All students experienced the activities: the two smaller sections (n=46) did not have the treatment whilst the larger third section (n=29) had the treatment. Data was collected from those students who submitted consent and assent forms for the control group (n=27) and the experimental group (n=22). For the control group participants, 20 students attended virtually and 7 attended face-to-face; for the experimental group, 16 students attended virtually and 6 attended face-to-face.

The identities of students were concealed by assigning project identification numbers on all collection items throughout the data collection. All documents, pretests/posttests, models and Metacognitive Maps, were labeled with the project identification number assigned for the study. Every student was assigned a number and was required to submit assignments, however, only students who had submitted permission forms from parents and consent forms for themselves had data entered for use in the study. Project identification numbers were used throughout the data analysis.

Instrumentation

Instrumentation and data sources include a metacognitive question guide (Metacognition Map), a scoring rubric to evaluate models, a pre-test and post-test of a chemistry concept, and the Metacognitive Activities and Perceptions Inventory (MCAPI). Each of these measures will be described in the follow sections.

The Metacognition Map

The Metacognitive Map instrument was developed by the researcher for use in the current study (see APPENDIX B). The questions within the Metacognition Map were founded on the work of Tanner (2012) who patterned types of questions to guide students toward metacognitive activity. The question types suggested by Tanner were adapted and placed into the format of a question guide for use alongside the modeling activities. The guiding questions prompted responses associated with the three regulatory tasks of metacognition identified by Bowen et al. (2017): planning, monitoring and evaluating. The Metacognition Map was used to enhance metacognitive instruction to the experimental group when students completed it alongside the construction and revision of five models.

Achievement Scores

Student achievement data was based on (a) pre-test and post-test, each comprised of 22 questions, on the misconceptions identified in the literature related to the concepts demonstrated by the chemical phenomenon (see APPENDIX C) and (b) five rubric scores from evaluation of the modeling exercises (see APPENDIX D for rubric and APPENDIX E for model instructions as appeared in the Formative app) and also (c) scores for the models constructed during the course unit test (see APPENDIX F for unit test questions). The specific pre-test/post-test was designed to evaluate misconceptions in the content area of solution chemistry; likewise, the phenomena that undergird the model constructions were selected to be appropriate for the content in solution chemistry.

Development of Pretest/Posttest Instrument. The performance measure to determine learning gains of students in the concepts of solution chemistry was based on specific misconceptions identified in the literature. The pretest and posttest were designed to target the misconceptions found in the literature about solution chemistry and the construction of the questions was sourced from sources having established reliability and validity as national tests. A written version is found in APPENDIX C however, the version delivered to students was delivered online via Formative app.

Adadan and Savasci (2012) noted alternative conceptions about the nature of solutions and dissolving in water such as solutes melting before dissolving into water or turning into liquid before mixing with water and even that solutes react with water. Calyk et al. (2005) describe the same misconception and note that particulate drawings and diagrams help students to express the correct concepts with more success. The pretest questions # 1-3 address these misconceptions with one question adapted from online quiz (Queensland Science Teachers, 2000) the second from an exam review (New Jersey Center for Teaching and Learning, 2014) and the final is a researcher generated question using a particulate drawing, representing the sub-microscopic level and equations representing the symbolic level.

Nakhieh (1992) reported student misconceptions of relating chemical equations to correct particulate drawings of a sub-microscopic system, (i.e., dissolving), and question # 3 addresses the appropriate equation for dissolving associated with the particulate representation of dissolving. Misconceptions regarding the dissolving of ionic substances have been documented and researchers have found that students struggle to understand the separation into ions by ionic compounds (Kelly et al., 2010; Naah & Sanger, 2012), have difficulty transferring the dissolving of the exemplar NaCl to other ionic salts (Devetak et al., 2009) and often fail to apply subscripts in ionic compound formulas to the number of ions produced in solution (Smith and Metz, 1996). Nakheih (1992) and Kabapanar et al. (2004) denote student difficulty with matching dissolving equations with submicroscopic representations and correctly depicted a hydration ring. Questions # 4-12 are about ions or electrolytes dissolving and were sourced from Noah and Sanger (2012), College Board (n.d.) multiple choice and Regents (2018, 2019).

Questions # 11 (Adadon & Savasci, 2012) and # 12, sourced from American Chemical Society Chemistry Olympiad (2012) are about saturation of solute in solution. Adadan and

Savasci (2012), Pinarbasi and Canpolat (2003), and Devetak et al. (2009) each addressed the misconceptions with understanding and representation of saturated solutions and supersaturated solutions noting that students will represent both types of solutions with identical drawings. The questions addressing gasses dissolved into solutions, # 13-16, concern misconceptions about gas solutes noted by Adadan and Savasci (2012). Colligative properties for solid and gas solutes are evaluated in questions # 17-22 where the inability to distinguish pure solvents and solutions by properties, a noted misconception, are examined (Adadan & Savasci, 2012; Pinarbasi & Canpolat, 2003). These questions, # 13-22, are sourced primarily from College Board (n.d.), Regents (n.d.), and American Chemical Society (n.d.) Chemistry Olympiad.

Rubric for Models. The modeling activity was scored using a rubric designed to evaluate the success of the model to communicate concepts evidenced in the chemical phenomenon (see APPENDIX D.). This evaluation rubric holds face validity and content validity emanating from its development by the researcher and two other colleagues, each veteran chemistry instructors, for the purpose of scoring student-made models in chemistry (Edwards et al., 2017). The rubric holds criterion validity since it was based on models exampled in the literature and cited at the foot of rubric including Merritt and Krajcik (2013), Merritt et al., (2008), Ngai et al. (2014) and, Sevian and Talanquer, (2014). The rubric addressed features of the models such as illustration of particles, use of spacing and/or size, use of motion/energy, particle interaction, number of particles depicted and use of levels of representation. Evaluation of the student models will supply the performance data on the quality of the student-created models.

The rubric used has reliability established by experts locally at the school through use by veteran chemistry instructors. Human error in evaluating the models using the rubric might become an issue and was minimized by having two instructors grade 5% of the models. Also, researcher bias, such as performance bias or measurement bias, could be introduced in the grading of the models thus another evaluator in addition to the researcher scored the rubrics to circumvent that possibility.

MCAPI. The third instrument, the MCAPI was used to collect data on the development of metacognition and students' perception of metacognition (see APPENDIX G). The MCAPI was adapted from the Metacognitive Activities Inventory (MCAI; Cooper & Sandi Urena, 2009) for this study by the researcher. The MCAI is a robust, reliable and validated assessment of metacognition in chemistry problem solving and has been shown to exhibit acceptable levels of internal consistency, reproducibility, face validity and construct validity for a college population (Cooper & Sandi-Urena, 2009). The MCAPI instrument was derived from the MCAI and modified to address the specific skill of modeling activity.

Adaptation of Survey Instrument for Study. Although the MCAI was tested with a college population, the reliability and validity of the MCAI is expected to translate in the MCAPI since both groups, college and honors chemistry undertake the same chemistry skills in modeling. The MCAI items on problem solving were adapted to address the different chemistry skill, modeling. MCAPI is comprised of 28 statements. Agreement with the items is indicated on a Likert scale from 1 (strongly disagree) to 6 (strongly agree). The first six items address student perceptions and were devised by the researcher. The subsequent twenty-two questions mirror the questions on the MCAI (Cooper & Sandi-Urena, 2009), but apply to modeling instead of to problem-solving in chemistry. Six of those questions are negatively phrased and reverse scored.

Subscales of MCAPI. The MCAI was adapted into the Metacognitive Activities and Perception Inventory, MCAPI, to fit the goal of two subscales: that of perception of value for metacognitive thinking and that of perception of metacognitive thinking processes applied to the skill of modeling. Within the second subscale of perception of metacognitive thinking skills, three components were present aligning with the Metacognitive Map, as follows: Planning, Moderating and Evaluating. These components reflect the three regulatory tasks of MS identified by Bowen et al. (2017) and used by Tanner (2012). See APPENDIX H for MCAPI organized by subscales and components. Reliability for the MCAPI was assessed; Cronbach alpha for subscale one measuring perception of value of metacognitive thinking, was .80 and Cronbach alpha for subscale two measuring perception of metacognitive thinking activities in modeling, was .90.

The subscale one of the MCAPI, concerning value of metacognitive thinking, was administered to the experimental group only in order to obtain feedback on student perceptions regarding the value of metacognition. The subscale two of the MCAPI measured the perception of metacognitive activities in modeling and was administered to the experimental group and the control group after the lesson cycle. Qualtrics was utilized to administer the survey and collect the data via the online platform of the program.

Course Unit Test Questions on Model Construction. The item scores on the unit summative evaluation, for the specific questions about model construction, were an additional source of data to make more robust the evidence produced by the rubric scores during the modeling learning cycle. Each question was fashioned after the modeling prompts in the model exercises and focused on the particular misconceptions addressed by the model constructions. See APPENDIX F.

Reliability and Ethical Considerations

The Hawthorne effect, brought on by awareness of being in a study, or the John Henry effect, marked by awareness of being in the control group, are potential threats to validity since the high school already has a competitive atmosphere (McCambridge et al., 2014). Limiting the information provided to students regarding the nature of the study and blinding the label of the groups should have avoided the experimental errors of those specific possible effects. Ethical issues, such as acquiring permission of all stakeholders and ensuring the appropriateness of the teaching strategy was addressed through the ethics review process by Institution Review Boards (IRBs). Approvals were obtained from the IRBs from the county school district, the high school administration, and the higher education institution prior to the implementation of the study. Informed consent forms and students assent forms were collected prior to the study (see Appendix XX??). All participant data was de-identified through a number assignment to students to use throughout the unit as part of ethical considerations.

The anticipated value of the teaching strategy was not limited to the experimental group. The metacognitive companion to modeling was introduced to the control group during activities later in the semester after the data collection for the research was complete. Thus, the potential benefit of the metacognitive instruction was made possible for all students participating in the study.

Procedures

For this study, the vehicle for eliciting experiences in metacognition within the chemistry classroom was for students to construct science particulate models in response to their observation of chemical phenomenon. In the quasi-experimental treatment, one class of students, the treatment group, were provided the direct support of metacognitive instruction prior to and during the modeling exercise, and two other classes comprising the control group, did not receive the support of direct instruction and guidance in metacognition.

Throughout the unit of study in solution chemistry, students in both the treatment group and the control group constructed models by drawing a particulate representation of a process or structure in response to a phenomenon demonstrating solution chemistry. During the construction of each model, students in the treatment group were guided towards reflecting on metacognition, as applied to the modeling activity in chemistry, when they completed the Metacognitive Map.

Procedures of Implementation

Length of Study. Lavi et al. (2019) recommend that a metacognitive assignment include aspects of knowledge (MK) and regulation of cognition (MS), group work and individual work, and a learning cycle that builds on the first metacognitive experience and transfers the metacognitive skill into a real-life situation. The design of the current study reflected an effort to accomplish these aspects. The study spanned over three weeks (15 school days) with research activities scheduled for ten of the 15 instructional days. The ten days were spread out over a three-week unit on solutions.

Pretest Administration. Before the treatment, students were given a pre-test on the chemistry misconceptions relating to the demonstrations of the chemical phenomenon. On Day 1, chemistry content pre-test was administered for both groups.

Treatment of Metacognitive Instruction. The metacognitive instruction received by the experimental group was via a PowerPoint introduction to metacognition and by use of a reflective question guide, also known as the Metacognitive Map, which was completed in tandem with the modeling activity. Students in the treatment group were presented with the concept of metacognition prior to the unit. The introduction to metacognition presentation was patterned after a PowerPoint presentation featured in the research of Cook et al. (2013); this study served as the precursor for this design of research because it documented the impact of a 50-minute lecture about metacognitive learning strategies on subsequent test performance for the experimental group (Cook et al., 2013). The PowerPoint presentation may be viewed in APPENDIX I. The question guide, entitled Metacognition Map, was designed to stimulate metacognitive processes of planning, regulating and evaluating and it recorded direct feedback from the students regarding the process of modeling during the modeling exercises.

Model Construction within the Unit. Students observed chemical phenomena as the springboard for their model construction. Students first constructed one model within a cooperative group and transitioned to independent work, five individual efforts. The cooperative groups used in the beginning of the study were guided by the format of schooling: all virtual students comprised a group and F2F students were divided in one to two groups.

The phenomena were predominantly physical change demonstrations illustrating concepts in solution chemistry. The modeling activities were embedded in an interactive digital format built in a platform, subscribed to by the school, called Formative. There were five Formative activity sets prepared with different types of questions, short videos and interactive sections. The group model and the five individual models were embedded into the Formatives. Each model was designed to address specific misconceptions and thus had specific pretest/posttest questions tied to the content explored by the model. See APPENDIX F.

Model representations of the different types of physical interactions when substances form solutions had the dual effect of deepening content knowledge and developing particulate representation via modeling. The phenomena, presented via curated videos, simulations and in-class demonstrations, addressed different aspects of solution formation including types of solvents, solvent-solute interactions and the effect of solutes on solvent properties. Also, the inclusion of one chemical change phenomenon in the introductory review promoted understanding of the contrast between physical and chemical changes. The three levels of chemistry representation were each represented as part of the modeling experience. The macro level was the phenomenon observed by students, the symbolic was equations or graphs or labeling and the submicroscopic was represented by the model construction. See Table 2 for the organization and details pertaining to the Formatives and the models.

Table 2

FORMATIVES: Solution Chemistry delivered through modeling and guided metacognition

Formative #	Misconception focus/ Other Topics What happens when a solute dissolves in a solvent? How can we represent this event?	Macro: Phenomenon	Sub-micro: Particulate Models	Symbolic	Pretest/ Posttest Items	FORM item: Graded	FORM item: Metacognitive Map use
1 What is a solution?	Dissolving VS Melting	Demo: sugar dissolving (video)	Model sugar dissolving	Equation	#1,2,3	# 13	# 12-13
	Types of mixtures Covalent compounds remain intact and are surrounded by water molecules Characteristics of solutions						
2 How are solutions formed?	Ionic pairing vs dissociation when dissolved Transfer of ionic understanding from NaCl to KBr	In-class DEMO: Adding ionic salt to water	Model ionic compound dissolving	Equation	#4,5,6	# 12	#11-12
	Ions produced by ionic compounds equal subscript number in formula. Electrolytes are both + and - particles	In-class DEMO: Adding ionic salts to water	Model covalent and ionic compounds dissolving	Describe macroscopic Equation	#7,8 #9,10	#16	#15-16
	Polarity effect on solutions Miscible/ soluble Ionic compounds dissociate when dissolved						
3 Why are solutions formed?	Increase rate does not equal increase in solubility	Demo: Solute dissolving in different conditions (Video)	Model different surface area dissolving for sugar solution	Equation		#13	#12-13
	Rate of dissolution and Effects on it Solvation steps Solvation energy						
4 How much solute can be dissolved?	Saturated solutions will have undissolved solute settle at bottom as paired ions and dissolved ions in solution; unsaturated have nothing at bottom. Temp inverse to solubility of gas	Saturated and unsaturated solutions made (Video)	Model unsaturated and saturated using amounts and solubility curve graph	Solubility Curve Graph Equation	#11,12 #13,14, 15,16	# 11	#10-11
	Solubility of solids and gases Supersaturation						
5 What are effects of solute?	Number of particles affect Colligative properties Vapor pressure is produced by solvent molecules above the solution/liquid	Animated vapor pressure for pure solvent and for solution	Model vapor pressure contrasting pure solvent, covalent solute and ionic solvent	Labeling pure substance vs. solution	#17,18, 19, 20 #21, 22	#15	#14-15
	Colligative properties Boiling and vapor pressure						

Cycle of Model Skill Development. The cycle of model skill development introduced one physical change phenomenon demonstration to model within the scope of solution chemistry on the initial day and the next day followed with whole group critique and revision. The students could volunteer to have the class focus on their model and this was accomplished by viewing the model within Formative as a class. Students were guided to share strengths and recommended additions of the model under review. With the feedback fresh, students had time to revise their own models. The revised model was submitted for scoring on the second day. The ten days of activity included in the research to extend over a fifteen-day unit allowed additional time for students to internalize the practice of modeling.

Students in the experimental group completed a Metacognitive Map for each of five individual models submitted for scoring. The experimental group had one additional instruction on each model to complete the Metacognitive Map and to upload it to TEAMS. Use of the Metacognitive Map each time, for individual models, was to strengthen the practice of new metacognitive skills.

Performance Data and Survey Data Collection. At the conclusion of the unit, a post-test on the misconceptions was administered to both groups and an administration of the subscale two of the MCAPI was given to students in the experimental group and to students in the control group; subscale one of the MCAPI was given to students in the experimental group. All models created were evaluated based on the rubric and scores classified by student number and by group.

Study Plan. The study plan is detailed in Table 3 with specific events, designated demonstrations and instruments used. For each day of the unit, the students were in hybrid instruction, some in face-to face instruction and some included via ZOOM in virtual setting, with normal period time slots. See Table 3.

Table 3

Study Plan

DAY	Event/ Activity
1	Administer Pre-test of content to control and experimental groups Show Metacognitive Presentation via PPT to experimental group
2	Lecture and Problem Practice
3	Formative 1 Introductory modeling exercise in cooperative groups: Modeling the physical change of melting Phenomena: Sugar melting in a spoon and then burning
4	Students critique and revise group models Formative 1 Modeling exercise independent work: Modeling dissolution of covalent substances Phenomena: Dissolving of sugar, $C_{12}H_{22}O_{11}$, in water Experimental group use Metacognitive MAP
5	Class critique and revision of individual models #1; submit model for scoring Formative 2 Modeling exercise independent work: Modeling dissolution of ionic substances Phenomena: Dissolving of salt, NaBr, in water Experimental group use Metacognitive MAP
6	Lecture and Problem Practice
7	Class critique and revision of individual models #3; submit model for scoring Formative 2 Modeling exercise independent work: Modeling dissolution of both ionic and covalent substances Phenomena: Dissolving of KCl, K_3PO_4, Fructose $C_6H_{12}O_6$ Experimental group use Metacognitive MAP individually
8	Class critique and revision of individual models #3; submit model for scoring Formative 3 (this model not included in rubric scoring nor data for study) Modeling exercise independent work: Modeling dissolution in different conditions and rate of solvation

	Phenomena: Dissolving of salt in different conditions of temperature and agitation
9	Concentrations Lab
10	Formative 4 Modeling exercise independent work: Saturated and unsaturated solutions Phenomena: Dissolving of solute in water to make saturated and unsaturated solutions Experimental group use Metacognitive MAP individually
11	Lecture and Problem Practice
12	Class critique and revision of individual models #4; submit model for scoring Formative 5 Modeling exercise independent work: Modeling colligative properties Phenomena: Animated vapor pressure for pure solvent and solution Experimental group use Metacognitive MAP individually
13	Class critique and revision of individual models #5; submit model for scoring Test Review
14	Unit Test
15	ADMINISTER 1. Post-test of content to control and experimental groups 2. Survey Instrument to control and experimental group

Data Analysis

All data were entered into SPSS software for screening and statistical analysis. As shown in the research alignment table (see Table 4), two statistical methods were used to analyze different data sets including independent sample t-tests and Pearson's correlations. To answer research question one (Does direct coaching or instruction of metacognition enhance modeling and the acquisition of the conceptual content?), bivariate analysis was conducted to compare experimental and control groups and to examine differences between the experimental group experiencing the metacognition instruction and the control group not experiencing it. The independent variable was the exposure to the metacognition presentation and guidance, and the dependent variables were the rubric scores for the model and test scores. Pre-test and post-test means were evaluated using independent sample t-test to compare learning gains. The normalized learning gain (Hake, 1889) is considered a rough measure of effectiveness of instruction in enhancing conceptual understanding and is utilized standardly for reporting scores on concept inventories in research. The pretest/posttest falls in this category as a measure on misconceptions in solution chemistry. Learning gains are described as the amount students learned divided by the amount they could have learned (McKagan et al., 2017). The normalized gain scores is calculated as $\langle g \rangle$ = (posttest – pretest) / (100 – pretest) (Hake, 1998).

To answer research question two (Does direct coaching or instruction of metacognition enhance student awareness of metacognitive thinking processes?), bivariate analysis was conducted to compare experimental and control groups for the MCAPI Subscale- Metacognitive Thinking to examine differences between the experimental group experiencing the metacognition instruction and the control group not experiencing it. To answer research question three (Is there a correlation between student perception of values of metacognitive activities and their awareness of metacognitive thinking processes?), Pearson Correlation was used to explore the correlation of MCAPI-Value and MCAPI- Metacognitive Thinking between the student perception of the value of metacognitive activities and student perception of metacognitive thinking processes for the experimental group. See Table 4 for a summary of research questions and analysis methodologies.

Table 4 Research Alignment

Research Question	Key Variables	Source of Instrument(s) or Measurement of the Key Variables	Sample Items and Reliability (Cronbach's alpha)	Scale	Measurement Type	Data Analysis Approach
(1) Does direct coaching or instruction of metacognition enhance modeling and the acquisition of the conceptual content?	Students' science modeling skills	Rubric for the Evaluation of Student Generated Particulate Models for both groups	Draw a particulate model depicting the solvation of the ionic salt KBr in water. Reliability established locally at the school by chemistry instructors and by scoring 5% of models and by another teacher	1-24 0-4	Continuous Variable Continuous Variable	Independent Sample t test Independent Sample t test
		Model construction items on unit test for both groups	Create a model to represent aqueous solutions of .10 M $AlBr_3$ and .20 M $C_{12}H_{22}O_{11}$.	1-100	Continuous Variable	Independent Sample t test
	Student's science content acquisition	Learning gains from misconception pre-test and post-test scores for both groups	The process of solute particles being surrounded by solvent particles is known as ____. a. melting b. solvation c. fusion d. dehydration Reliability established through sources of national tests			
(2) Does direct coaching or instruction of metacognition enhance student awareness of metacognitive thinking processes?	Student awareness of metacognitive thinking processes	MCAPI, Metacognitive Activities & Perception Inventory based on MCAI (Cooper & Sandi-Urena, 2009) for both groups	Subscale 2- Metacognitive Thinking (22 items) 'I plan how to solve a problem before I actually start solving the problem' High reliability shown by Cronbach's coefficient All items $\alpha \geq .898$	1-6 Likert-type scale	Interval Variable with the Construct Mean Score	Independent Sample t test

(3) Is there a correlation between student perception of values of metacognitive activities and their awareness of metacognitive thinking processes?	Student perception of values of metacognitive activities	MCAPI, Metacognitive Activities & Perception Inventory based on MCAI (Cooper & Sandi-Urena, 2009) for experimental group	Subscale 1- Values (6 items) 'I think using metacognitive strategies could help me to learn.' Reliability shown by Cronbach's coefficient All items $\alpha \geq .801$	1-6 Likert-type scale	Interval Variable with the Construct Mean Score	Pearson Correlation of MCAPI-Value and MCAPI-Metacognitive Thinking r values $\alpha = 0.05$

Anticipated Results

Effect of Direct Instruction of Metacognition on Modeling

Data did undergo bivariate analysis to compare experimental and control groups for on modeling rubric scores for the model to examine differences between the experimental group experiencing the metacognition instruction and the control group. The independent variable was exposure to the metacognition presentation and guidance, and the dependent variable was the rubric scores. SPSS was used to enter data and to determine differences between the treatment group, receiving the presentation of metacognition, and the control group on the performance of the models. Means of the two groups were compared through a t-test.

Hypotheses

H_o: Modeling scores for control group = Modeling scores for experimental group

H_a : Modeling scores for control group ≠ Modeling scores for experimental group

$\alpha = 0.05$

Effect of Direct Instruction of Metacognition and Modeling on Learning Gains

Pre-test and post-test data of both groups was compared to examine the possible effect of modeling and metacognition on learning gains. The independent variable was exposure to the metacognition presentation and guidance and the dependent variable was the normalized gain scores calculated as $\langle g \rangle$ = (posttest – pretest) / (100 – pretest). An independent samples t-test was conducted to determine a ρ value to validate support of a conclusion.

Hypotheses

H_o: Mean of normalized learning gain for control group = Mean of normalized learning gain for experimental group

H_a : Mean of normalized learning gain for control group < Mean of normalized learning gain for experimental group

$\alpha = 0.05$

Effect of Direct Instruction of Metacognition on Metacognitive Thinking Processes

The data from the post survey MCAPI - metacognitive thinking processes subscale was compared across groups to examine the possible effect of direct instruction and coaching of metacognition on student perceptions of metacognitive thinking processes. The independent variable was the use of direct instruction and coaching of metacognition to deepen practice of metacognition and the dependent variable was the MCAPI scores. An independent sample t-test was conducted to determine a ρ value to validate support of a conclusion.

Hypotheses

H_o: Mean of Survey for Control Group = Mean of Survey for Experimental Group

H_a : Mean of Survey for Control Group < Mean of Survey for Experimental Group

$\alpha = 0.05$

Correlation between MCAPI Subscales of Experimental group

Bivariate analysis was also conducted between the two continuous variables of the subscale MCAPI-Value and subscale MCAPI- Metacognitive Thinking of the experimental group to determine the Pearson's r correlation coefficient through SPSS analysis.

Hypotheses

H_o: ρ = o

H_α : ρ ≠ o

α = 0.05

Chapter Four: Results

Confirming Equivalence Before Intervention

The data was collected from a sample of honors chemistry students on their scores for the pretest assessment (APPENDIX B) based on misconceptions in solution chemistry. For the pretest, the mean score for the control group (n=26) was 45.12 with a standard deviation of 13.50 and the mean score for the experimental group (n=21) was 41.95 with a standard deviation of 14.26.

Pretest scores were normally distributed for both groups, as assessed by Shapiro-Wilks test (p> .05) and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances (p=.99). Therefore, an independent t-test was run on the data with a 95% confidence interval (CI) for the mean difference.

Table 5

Independent Sample T-Test of Mean Comparison for Pretest Scores

Group	**Control (27)**		**Experimental (22)**		**t (45)**	**p**	**Cohen's d**
	Mean	SD	Mean	SD			
	45.12	13.50	41.95	14.26	.78	>0.05	.23

When compared the two pretest means in our sample, the independent-sample t-test was shown to be not statistically significant (t= .78, df =45, p>.05, one-tailed). The insignificant difference between control and experimental groups indicated the equivalence is confirmed before intervention was implemented. The groups are similar in size and equivalence is confirmed before comparisons between the two groups are made in subsequent analysis.

Research Question One: Metacognition Enhancement

Independent sample t-tests were used to answer the research question one: Does direct coaching or instruction of metacognition enhance modeling and the acquisition of the conceptual content?

Metacognition Enhancement of Modeling

The research question was answered by examining the 1) rubric scores and 2) summative unit test between the control and experimental groups. Peer scoring of 5% of the models scored was implemented to fortify the reliability of the rubric use. Inter-rater reliability was established at 42% agreement rate and confirmed with Cohen's Kappa, $\kappa = .34$ (95% CI) $p < .001$, which represents a fair strength of agreement (McHugh, 2012).

The modeling rubric overall mean score for the control group (n=27) was 19.55 with a standard deviation of 1.96 and the modeling rubric overall mean score for the experimental group (n=22) was 20.84 with a standard deviation of 1.68. Rubric means scores were normally distributed for both groups, as assessed by Shapiro-Wilks test ($p> .05$) and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances ($p=.53$). Therefore, an independent t-test was run on the data with a 95% confidence interval (CI) for the mean difference. See Table 6 for the analysis of performance data for modeling.

When compared these two means in our sample, the independent-sample t-test was shown to be statistically significant ($t= -2.43$, $df =47$, $p=0.0095$, one-tailed). In conclusion, we reject the null hypothesis that the modeling scores for control group will equal the modeling scores for experimental group. The 95% confidence interval is between -2.35 and -0.22. The effect size for this analysis (d = .70) was found to exceed Cohen's (1988) convention for medium effect (d = .50).

Table 6

Independent Sample T-Test of Mean Comparison for Rubric Scores

Group	**Control (27)**		**Experimental (22)**		**t (47)**	**p**	**Cohen's d**
	Mean	SD	Mean	SD			
	19.55	1.96	20.84	1.68	-2.43	0.22	.70

The rubrics were examined individually to compare means and analyze differences between the control and experimental group performances in modeling. The modeling rubric mean scores showed an increase for both groups from rubric one to rubric five as seen in Table 7. The means for the experimental group were higher than for the control group for each rubric score.

Rubric One. The mean score for modeling rubric one for the control group (n=26) was 17.54 with a standard deviation of 2.47 and the mean score for the experimental group (n=22) was 19.09 with a standard deviation of 2.83. Rubric means scores were normally distributed for both groups, as assessed by Shapiro-Wilks test (p> .05) and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances (p=.54). Therefore, an independent t-test was run on the data with a 95% confidence interval (CI) for the mean difference. When compared these two means in our sample for rubric one, the independent-sample t-test was shown to be statistically significant (t= -2.03, df =46, p=0.024, one-tailed). In conclusion, we reject the null hypothesis that the modeling scores for control group will equal the modeling scores for experimental group. 95% confidence interval is between -3.09 and -

0.014. The effect size for this analysis (d = .59) was found to exceed Cohen's (1988) convention for medium effect (d = .50).

Table 7

Independent Sample T-Test of Mean Comparison for Rubric Scores

Variable	n	M	SD	t	p	Cohen's d
Rubric 1				-2.03	<0.05*	.59
Control	26	17.54	2.47			
Experimental	22	19.09	2.83			
Rubric 2				-.128	>0.05	.037
Control	27	18.74	18.86			
Experimental	22	3.00	3.72			
Rubric 3				-2.03	>0.05	.84
Control	26	19.77	20.68			
Experimental	22	3.14	2.06			
Rubric 4				-3.16	<0.01**	.91
Control	26	19.89	22.41			
Experimental	22	2.98	2.50			
Rubric 5				-1.81	<0.05*	.52
Control	26	21.85	2.28			
Experimental	22	23.14	2.79			

* significance of correlation $\rho < .05$
** significance of correlation $\rho < .01$

Rubric Two. The mean score of modeling rubric two for the control group (n=27) was 18.74 with a standard deviation of 3.00 and the mean score for the experimental group (n=22) was 18.86 with a standard deviation of 3.72. Rubric means scores were normally distributed for both groups, as assessed by Shapiro-Wilks test (p> .05) and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances (p=.13). Therefore, an independent t-test was run on the data with a 95% confidence interval (CI) for the mean difference. When compared these two means in our sample for rubric two, the independent-sample t-test was shown to be not statistically significant (t= -.128, df =47, p=0.45, one-tailed). In conclusion, we do not reject the null hypothesis that the modeling scores for control group will equal the modeling scores for experimental group. 95% confidence interval is between -2.05 and 1.81. The effect size for this analysis (d = .037) was found below Cohen's (1988) convention for small effect (d = .037).

Rubric Three. The mean score of modeling rubric three for the control group (n=26) was 19.77 with a standard deviation of 3.14 and the mean score for the experimental group (n=22) was 20.68 with a standard deviation of 2.06. Rubric means scores were normally distributed for both groups, as assessed by Shapiro-Wilks test (p> .05) and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances (p=.06). Therefore, an independent t-test was run on the data with a 95% confidence interval (CI) for the mean difference. When compared these two means in our sample for rubric three, the independent-sample t-test was not shown to be statistically significant (t= -1.17, df =46, p=0.13, one-tailed). In conclusion, this result does not support rejection of the null hypothesis that the modeling scores for control group will equal the modeling scores for experimental group. 95% confidence interval is between -2.49 and .662. The effect size for this analysis (d = .84) was found to exceed Cohen's (1988) convention for large effect (d = .80).

Rubric Four. The mean score of modeling rubric four for the control group (n=27) was 19.89 with a standard deviation of 2.98 and the mean score for the experimental group (n=22) was 22.41 with a standard deviation of 2.50. Rubric means scores were not assessed as normally distributed for both groups, as assessed by Shapiro-Wilks test (p< .05), and there was homogeneity of variance as assessed by Levene's Test for Equality of Variances (p=.44).

Although the assumption of the t-test is normal distribution for dependent variables, it is considered a fairly reliable measure for nonnormal, mound shaped distributions and is robust even if the assumption is violated (Coolidge, 2013, p. 227). Additionally, parametric analysis for groups means, such as t-tests, is robust even though normality assumption is violated when each group has more than fifteen members and the group has considerably equal sample size within 1 to 1.5 ratio (Rasch et al., 2007). Therefore, an independent t-test was conducted on the data with a 95% confidence interval (CI) for the mean difference. When compared these two means in our sample for rubric four, the independent-sample t-test was shown to be statistically significant ($t= -3.16$, $df =47$, $p=0.001$, one-tailed). In conclusion, we reject the null hypothesis that the modeling scores for control group will equal the modeling scores for experimental group. 95% confidence interval is between -2.49 and .662. The effect size for this analysis ($d = .91$) was found to exceed Cohen's (1988) convention for large effect ($d = .80$).

Rubric Five. The modeling rubric five mean score for the control group ($n=27$) was 21.85 with a standard deviation of 2.28 and the modeling rubric average mean score for the experimental group ($n=22$) was 23.14 with a standard deviation of 2.70. Rubric means scores were not assessed as normally distributed for both groups, as assessed by Shapiro-Wilks test ($p< .05$) and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances ($p=.62$). Although the assumption of the t test is normal distribution for dependent variables, it is considered a fairly reliable measure for nonnormal, mound shaped distributions and is robust even if the assumption is violated (Coolidge, 2013, p. 227). Additionally, parametric analysis for groups means, such as t-tests, is robust even though normality assumption is violated when each group has more than fifteen members and the group has considerably equal sample size within 1 to 1.5 ratio (Rasch et al., 2007). Therefore, an independent t-test was conducted on the data with a 95% confidence interval (CI) for the mean difference. When compared these two means in our sample for rubric five, the independent-sample t-test was shown to be statistically significant ($t= -1.81$, $df =47$, $p=0.039$, one-tailed). In conclusion, we reject the null hypothesis that the modeling scores for control group will equal the modeling scores for experimental group. 95% confidence interval is between -1.29 and .711. The effect size for this analysis ($d = .52$) was found to exceed Cohen's (1988) convention for medium effect ($d = .50$).

Samples of students' model construction may be viewed from Appendix K. Samples from all classes are provided. The models are labeled for control group and experimental group. Each of the five assignments graded by the rubric are represented in the examples shown.

Additional Findings. The data was collected from the same sample of students for the scores on three modeling questions evaluated on the summative unit test for solutions and the scores were averaged. The summative model construction items mean score for the control group ($n=27$) was 3.22 with a standard deviation of .64 and for the experimental group ($n=22$) was 3.57 with a standard deviation of 0.44. Summative item scores were normally distributed for both groups, as assessed by Shapiro-Wilks test ($p> .05$) and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances ($p=.11$). Therefore, an independent t-test was run on the data with a 95% confidence interval (CI) for the mean difference. See Table 8 for the analysis of performance data for modeling on unit summative.

When compared these two means in our sample, the independent sample t-test was shown to be statistically significant ($t=-2.21$, $df = 47$, $p= 0.016$, one-tailed). In, conclusion, the mean score difference for the control and experimental group were statistically significant. 95%

confidence interval is between -0.67 and -.031. The effect size for this analysis (d = 0.55) was found to exceed Cohen's (1988) convention for medium effect (d = .50).

Table 8

Independent Sample T-Test and Mean Comparison for Model Construction on Unit Test

Variable	n	M	SD	t	p	Cohen's d
Test Items				-2.21	<0.05*	.63
Control	27	3.22	.64			
Experimental	22	3.57	.44			
Test Item 8						
Control	27	3.09				
Experimental	22	3.76				
Test Item 15						
Control	27	3.51				
Experimental	22	3.57				
Test Item 24						
Control	27	3.17				
Experimental	22	3.39				

* significance of correlation $\rho < .05$

Metacognition Enhancement of Content Acquisition

Posttest on misconceptions in solution chemistry was collected from both control and experimental groups. The mean score for the control group (n=26) was 77.50 with a standard deviation of 12.86 and the mean score for the experimental group (n=22) was 80.23 with a standard deviation of 15.63. Posttest scores were normally distributed for both groups, as assessed by Shapiro-Wilks test (p> .05) and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances (p=.33). Therefore, an independent t-test was run on the data with a 95% confidence interval (CI) for the mean difference. See Table 9 for the analysis of performance data for posttest.

Table 9

Independent Sample T-Test of Mean Comparison for Posttest

Group	**Control (27)**		**Experimental (22)**		**t (46)**	**p**	**Cohen's d**
	Mean	SD	Mean	SD			
	77.50	12.86	80.23	15.32	-.66	>0.05	.76

* significance of correlation ρ < .05

When compared the two posttest means in our sample, the independent-sample t-test was shown to be not statistically significant (t= -.66, df =46, p>.05, one-tailed). The scores for the pretest and posttest for the control and experimental group were not significantly unequal. The effect size for this analysis (d = 0.76) was found to exceed Cohen's (1988) convention for medium effect (d = .50).

The data was further analyzed on their normalized learning gains from a pretest and posttest based on misconceptions in solution chemistry. The normalized learning gain (Hake, 1998) is calculated as $\langle g \rangle$ = (posttest – pretest) / (100 – pretest). The pre and posttest scores for both groups along with learning gains score are reported in Table 9.

Learning gain scores were normally distributed for both groups, as assessed by Shapiro-Wilks test (p> .05) and that there was homogeneity of variance as assessed by Levene's Test for Equality of Variances (p=.31). Therefore, an independent t-test was run on the data with a 95% confidence interval (CI) for the mean difference. See Table 10 for the analysis of normalized learning gains data for pretest/posttest.

The normalized learning gains for both groups, $\langle g \rangle_{experimental}$ = 0.65 and $\langle g \rangle_{control}$ = 0.60, indicate a medium learning gain since the value falls in the range 0.7 > $\langle g \rangle$ > 0.3 (Pentecost & Barbera, 2013). However, the mean learning gain score for the control group (n=25) was 0.60

with a standard deviation of 2.25 and the learning gain mean score for the experimental group (n=21) was .65 with a standard deviation of 0.27. When compared these two means in our sample, the independent-sample t-test was shown to be not statistically significant (t= -.676, df =44, p>.05, one-tailed). The effect size for this analysis (d = .20) was found to equal Cohen's (1988) convention for small effect (d = .20). In conclusion, we fail to reject the null hypothesis that the learning gains for control group will equal the learning gains for experimental group. 95% confidence interval is between -0.19 and 0.097.

Table 10

Normalized Learning Gains Analysis for Solutions Chemistry Pretest/Posttest

Variable	n	M	SD	t	p	Cohen's d
Learning Gains				-.68	>0.05	.20
Control	25	.60	.22			
Experimental	21	.65	.27			
Pretest scores				.78	>0.05	.23
Control	25	45.12	13.50			
Experimental	21	41.95	14.26			
Posttest scores				-.66	>0.05	.76
Control	25	77.50	12.86			
Experimental	21	80.23	15.63			

* significance of correlation $\rho < .05$

Research Question Two: Direct Instruction of and Awareness of Metacognition

Independent sample t-test were used to answer the research question two: Does direct coaching or instruction of metacognition enhance student awareness of metacognitive thinking processes? The data was collected from a sample of honors chemistry students on their perception of metacognitive activities in modeling contributing to metacognitive thinking processes through MCAPI Survey. The survey subscale on metacognitive thinking processes mean score for the control group (n=26) was 5.02 with a standard deviation of 0.67 and the survey subscale on metacognitive thinking processes mean score for the experimental group (n=21) was 4.92 with a standard deviation of 0.45. Homogeneity of variance was assessed by Levene's Test for Equality of Variances (p=.26). A Shapiro – Wilks test showed a significant departure from normality for the control group, W (26) = .91, p= .03 although the normality assumption is only needed for small sample sizes of n < 20. For larger sample sizes, the sampling distribution of mean is always normal regardless of how the values are distributed according to central limit theorem (Shapiro -Wilks Test, n.d.). A Shapiro – Wilks test showed normality for the experimental group, W (21) = .94, p= .25. Therefore, an independent t-test was conducted on the data with a 95% confidence interval (CI) for the mean difference. See Table 11 for the analysis of metacognitive thinking skills by independent sample t-test.

Table 11

Metacognitive Thinking Skills on MCAPI Analysis

Group	**Control (26)**		**Experimental (21)**		**t (45)**	**p**	**Cohen's d**
	Mean	SD	Mean	SD			
	5.02	.68	4.92	.45	.57	>0.05	.59

* significance of correlation ρ < .05

When compared these two means in our sample, the independent-sample t-test was shown to be not statistically significant (t= .57, df =45, p>.05, one-tailed). The effect size for this analysis (d = .59) was found to exceed Cohen's (1988) convention for medium effect (d = .50).

In conclusion, we fail to reject the null hypothesis that the mean of metacognitive thinking processes for control group for control group will equal to the for experimental group.

95% confidence interval is between -0.25 and 0.44. In other words, there is no significant difference on student awareness of their metacognitive thinking processes shown in the study between control and experimental groups.

Research Question Three: Value and Awareness Correlation in Experimental Group

Pearson's correlation was used to answer research question three: Is there a correlation between student perception of values of metacognitive activities and their awareness of metacognitive thinking processes?

The data was collected from a sample of honors chemistry students in the experimental group on their perception of value of metacognition and their perception of metacognitive activities in modeling contributing to metacognitive thinking processes through MCAPI. The subscale on value of metacognitive activities mean score for the experimental group (n=22) was 4.64 with a standard deviation of 0.76 and the subscale on metacognitive thinking processes mean score for the experimental group (n=21) was 4.92 with a standard deviation of 0.45. When examined these two means in our sample for correlation, results of the Pearson correlation indicated that there was a significant positive association between student perception of value of metacognition and perception of metacognitive thinking processes, (r (21) = 0.48, ρ = .015). See Table 12.

According to Cohen's d (Cohen, 1992), the correlational relationship is moderate in strength (r = .48). In conclusion, we reject the null hypothesis that correlation $\rho = 0$. In other words, there exists a moderate positive relationship between the student value of metacognition and the student awareness of metacognitive thinking skills.

Table 12

Summary of Correlation Coefficients for Experimental group MCAPI (N=21)

Variables	Mean (SD)	Correlation with Value Q1-Q6 Pearson Correlation	Correlation with Value Q1-Q6 Significance
Value	4.64 (.76)		
Metacognitive Thinking Processes	4.92 (.45)	0.48*	$\rho = 0.015$

* significance of correlation $\rho < .05$

Chapter Five: Discussion

The purpose of the study was to examine the interplay between science modeling and direct instruction in metacognition. The quasi-experimental study was designed to investigate how students' skill in science modeling was bolstered by the fortification of increased metacognitive skill and how each strategy, science modeling and metacognition, augmented the acquisition of chemistry content. Further, perceptions of metacognitive value and of metacognitive thinking processes were appraised in conjunction with the fortification of metacognitive skill due to direct metacognitive cultivation. The goal of the study was to address the following research questions:

1. Does direct coaching or instruction of metacognition enhance modeling and the acquisition of the conceptual content?
2. Does direct coaching or instruction of metacognition enhance student awareness of metacognitive thinking processes?
3. Is there a correlation between student perception of the value of metacognitive activities and their awareness of metacognitive thinking processes?

Direct Instruction of Metacognition Enhances Modeling

The cultivation of metacognitive skill by means of direct instruction in the PowerPoint Presentation and of guidance through the Metacognitive Maps was shown to have a significant enhancement for modeling in the experimental group. Each group demonstrated an increase in rubric scores from rubric one to rubric five and from each rubric to the next one. Student skill in modeling was shown to grow for each group as they progressed from one modeling task to another and experienced the modeling cycle. The independent sample t-tests for both the model rubric mean scores and the unit test models mean scores indicated greater mean scores for the experimental group and the greater means were shown to be significant differences for the experimental group by comparison to the control group. The medium effect size indicated by Cohen's d reveals that the students in the experimental group were more likely to have better rubric scores. The outcomes from the statistical analysis, manifesting significant differences, leads to findings concluding the direct cultivation of metacognition, contextualized in the modeling skill development, enhanced the modeling skill for the experimental group.

Rubric mean scores for each rubric were analyzed and the means for the experimental group were higher in each rubric than the control group means. However, rubrics one, four and five indicated statistically significant differences between the control and experimental group yet rubrics two and three were not shown to have significant differences. All rubric scores, but rubric two, demonstrated a medium or large effect size as identified by the Cohen's d. The experimental group thus exhibited initial notable higher performances followed by similar performances for rubric two and rubric three and then exhibited the higher performances again in the final two rubrics. Models for rubric three, four and five were based on phenomena more complex in nature although the same characteristics were evaluated for all models. The reflection undertaken on the Metacognitive Maps which accompanied all model construction for the experimental group was a likely bolster of the skill of the experimental group as the modeling demands grew steeper.

The significant findings based on the modeling rubric score means, both the average of combined rubric scores and the individual means of rubric one, four and five, support the main thrust of the hypothesis that direct cultivation of metacognition contextualized within the science skill of modeling will bolster the science skill. The enhancement of the growth in modeling skill by co-joining it with metacognition was the central goal of the study. The findings based on the three models assessed on the unit test were sought in to make more robust the initial findings of the rubric score analysis. The analysis of the items from the unit summative test echoed the statistically significant difference in performance for the experimental group when compared to the control group. The conclusion that metacognitive cultivation bolstered the science skill of modeling is warranted.

Mixed Results of Modeling Effects on Content Acquisition

The independent sample t-test for normalized learning gains did not exhibit statistically significant differences between the experimental group and the control group. Learning gains were measured based on the pretest/posttest mean scores. The experimental group did demonstrate a higher mean score indicating a learning gain of 65% compared to the learning gain of the control group of 60%. Yet the difference was not determined to be statistically significant.

The normalized learning gain is an important finding as it demonstrates the effectiveness of the modeling exercises, which were founded on phenomenon demonstrating specific areas of misconception, as one that produced medium learning gains. Although, it may be concluded that the treatment of direct metacognitive cultivation for the experimental group did not produce statistically significant differences from the control group, nonetheless, both groups experienced learning gains considered a medium learning gain since the value falls in the range $0.7 > \langle g \rangle > 0.3$.

The pretest/posttest, founded on misconceptions documented in the literature and specifically addressed by the modeling exercises, may not reflect overall content knowledge gained in the unit pertaining to solution chemistry. There were other concepts in solution chemistry that have not been identified as specific misconceptions and were evaluated as a part of each student's summative representation for the unit. A comparison of scores on the full content of the solution unit reflected by the unit summative test might have provided more detail to the overall comparison of control group and experimental group in content acquisition.

Another factor bearing on the results was that the experimental and the control groups were both comprised of highly motivated honors students who demonstrated very similar performances in learning gains; that was perhaps connected to shared characteristics of honors students. It is also worth noting that since the pretest/posttest were conducted within a computer platform for both face-to-face and virtual students, the opportunity for all students to screen shot the questions during the pretest in preparation for the posttest made the performance scores less dependable than in a normal school year when test documents are delivered in a more secure format.

Unpacking Metacognitive Thinking Processes from the Survey Results

The students were surveyed at the completion of unit on their awareness or perception of their metacognitive thinking processes. Students from the experimental group had been exposed to the concept of metacognition and had reflected upon the MS tasks during each modeling cycle however those activities did not seem to enhance their awareness of metacognition more than that of the control group.

Comparison of survey results on MCAPI for the subscale two, perceptions of metacognitive thinking processes, between experimental group and control groups did not produce a statistically significant difference in the metacognitive thinking processes mean scores. The mean score of the control group was higher but the differences were not statistically significant. The conclusion from the analysis was that the two groups perceived their metacognitive thinking processes when applied to the modeling exercises with similar responses despite the treatment of the experimental group who were introduced to metacognition through direct instruction and five Metacognitive Maps during the modeling exercises.

Metacognitive Thinking Processes and Awareness in Survey

However, the two groups perceived metacognitive thinking activities with mean scores of 5.0/6 and 4.9/6 indicating a strong positive awareness of their metacognitive processes. It is likely that the students already possessed a level of awareness regarding metacognition or perhaps the modeling activity cycle elicited metacognitive thinking processes with or without the conscious awareness of metacognition inspired by the completion of the Metacognitive Maps.

Value and Thinking Processes Correlations in Experimental Group

The correlation analysis of the MCAPI revealed significant relationships predicted by the research hypotheses. A strong statistically significant positive correlation for the experimental group was seen in the relationship between subscale one, perception of value of metacognition and subscale two, perception of metacognitive thinking processes. It can be concluded that there is a statistically significant relationship for the experimental group between perception of value of metacognition and perception of metacognitive thinking processes. Students who were exposed to direct guidance in metacognition exhibited value correlated to their awareness of metacognition.

Implications of Findings and Connections with Prior Literature

Students experienced scientific inquiry, as defined earlier, given that each lesson originated with a question about solution chemistry and sought an answer through evidence of the phenomenon to support the construction of an explanation in the format of a particulate model. The model (explanation) constructed by the student was communicated through sharing the visual representations, the models, with the class and instructor. The models underwent critique by the class and revision to become a refined, justifiable answer to the question. The normalized learning gain means, $\langle g\rangle_{experimental} = 0.65$ and $\langle g\rangle_{control} = 0.60$, indicated a medium performance in the elimination of misconceptions in solution chemistry. The answers internalized by the modeling process contributed to the learning gains. Thus, the scientific inquiry approach to learning via observation and modeling (Louca & Zacharia, 2021) was shown an effective pedagogy.

Students produced models consistent with the definition to explain and predict through representation something in the natural world; their models show how something they observe through the phenomenon works the way the way it does (White et al, 2009). Since modeling is the construction and revision of a representation to communicate the characteristics of an event and/or relationships between components of a system with explanatory and predictive capability (Cooper et al., 2017; Kokkonen, 2017), the students constructed initial models, experienced social constructivism (Colburn, 2007) when working with peers to isolate strengths and weaknesses in their models in class and submitted final revised models for scoring. The social constructivism in place and inquiry-based reflection through revision produced active knowledge construction in keeping with the inquiry methodology (Akuma & Callaghan, 2018; Mupira & Ramnarain, 2017).

Students experienced the modeling cycle supported in the literature (Kokkonen, 2017). Components of the modeling exercises not only incorporated a cycle of observation-construct-review-revise noted to be critical to modeling skill development (Kokkonen, 2017), the phenomenon were curated to develop key concepts in solution chemistry (Santos & Arroio, 2016) and dispel literature-based misconceptions. Moreover, the modeling exercises fulfilled the theoretical platform of the chemistry triplet of representation (Johnstone, 1993; Talanquer, 2011)): the macroscopic representation was presented through the phenomenon, the symbolic representation was fulfilled with the required equations, specific labels and use of graph on one exercise and the model construction covered the submicroscopic representations.

The effect of the modeling cycle was noted in the achievement of the student modeling seen for both groups since both groups showed continual increase from one rubric to the subsequent. Examples of the revised models produced from observation of the phenomenon to explain phenomenon event at the particulate level are found in APPENDIX J.

The deliberate and careful design of the modeling exercises to correspond to misconceptions and to include movement between the three representational levels fortified the capacity of the exercises to increase learning of chemistry (Louca & Zacharia, 2012) in tandem with the strengthening of metacognition (Thomas & Anderson, 2014). Metacognition, defined as "individuals' knowledge, control and awareness of cognition" (Thomas & McRobbie, 2013, p. 302), manifested in the study. Both groups perceived metacognitive thinking activities with mean scores of 5.0/6 and 4.9/6 indicating a strong positive awareness of their metacognitive processes. As students learned how to produce quality observation and precise representation in modeling, they acquired new thinking strategies, monitored task performance and made changes to counter feedback; each of these is an aspect of metacognition (Hacker, 2009; Zohar & David, 2008). The direct cultivation of metacognitive skills (Cook et al., 2013) did not produce statistically significant differences in metacognitive awareness for the experimental group.

However, the impact of the modeling exercises, experienced by both groups, on the perception of metacognitive thinking processes may have overshadowed the influence of direct cultivation of metacognition, the treatment only the experimental group experienced. Presenting a challenge to chemistry students such as modeling, based on a phenomenon, and revising the model, after critique, was an exceptional opportunity to elicit ME, precisely because it is a novel encounter delivering cognitive imbalance (Sandi-Urena et al.,2011; Zohar & David, 2009). The modeling activity cycle delivered an activity to draw out ME, with the potential to elicit MS (Bowen, et al., 2017). As students interpreted a phenomenon, created a model and refined a model, they used the judgments and estimates that comprise ME. ME has the potential to sharpen MS as students develop and apply appropriate strategies to the novel encounter (Graham et al., 2019; Thomas & McRobbie, 2013). The modeling cycle contextualized ME (Rahmen et al, 2010) and made powerful the potential for metacognitive growth (Crick, 2013; Zohar & David, 2009).

The positive scores for subscale two of MCAPI, perceptions of metacognitive thinking processes, for both groups displayed similarities with no statistically significant difference. This finding suggests the power of the modeling exercises to elicit metacognitive growth may have outweighed the influence of the direct metacognitive cultivation treatment of the experimental group. The modeling cycle may have benefitted the development of metacognition which could have been revealed in the metacognitive awareness of both groups. The connection between modeling, specifically sub-microscopic representation as constructed by the students, and metacognition has been noted in the literature (Louca & Zacharia, 2012; Thomas & Anderson, 2012). Oher interventions in chemistry instruction have been shown to produce ME and have demonstrated that science inquiry methods have a beneficial enhancement of metacognition (Casselman & Atwood, 2017; Cooper & Sandi-Urena, 2009; Thomas & McRobbie, 2013)

Based on the literature, the researcher hypothesized that direct cultivation of metacognition could result in higher performance, even if delivered over a shorter period of time, as seen in this study. Achievement scores on tests (Casselman & Atwood, 2017; Cook et al., 2013; Zepeda, et al., 2015) were increased in these studies utilizing a short treatment of metacognitive cultivation. Other studies of longer length of treatment also saw gains in performance data (Graham et al., 2019; Seraphin et al., 2012; Thomas & McRobbie, 2013).

The aim of the metacognitive cultivation, activated through the PowerPoint presentation and the reflection prompted by the Metacognitive Maps, was the specific performance data of the model scores. It was a novel contextualization to integrate the nurturing of metacognition with an SEP, the science skill of modeling. The performance increase of the experimental group, indicated by the achievement data of the model scores during the unit and the model scores on the unit summative, was statistically significant in its difference from the control group. The significant differences shown for the experimental group in overall model performance and in rubrics one, four and five support the effectiveness of the treatment to bolster the skill thus producing a robust claim of the capacity for enhancing performance engendered by direct cultivation of metacognition contextualized into a content skill (Chick, 2013).

The potential of modeling to reveal and address content misconceptions was put forth in literature (Cooper et al.,2017; Santos & Arroio, 2016; Sujak & Daniel, 2017), as well as, the power of modeling to enhance understanding of chemistry (Edwards & Head, 2016; Kimberlin & Yezierski, 2016; Okumus et al., 2019). The learning gains exhibited by both groups confirmed the expectation of the literature that modeling would enhance learning and reduce misconceptions.

Conceptual Framework Revisited

The conceptual framework anticipated the increase in performance for the modeling achievement scores through the research question one. Affirmation of the portions of the hypothesis regarding the strengthening of modeling as reflected by increased student mastery in model construction was accomplished through the study. Research question three about the correlation of perception of value and perception of thinking processes for metacognition was answered with a positive relationship for the experimental group.

The conceptual framework did not address the possible dominance of the metacognitive development produced by the modeling exercises that perhaps eclipsed the direct cultivation treatment in enhancing learning gains and promoting metacognitive awareness. Given that both groups underwent the modeling exercises with the result of demonstrating similar means in learning gains scores for content misconceptions and similar means in perception of metacognitive thinking processes, the catalyst for growth could have been the modeling exercises. Scientific inquiry strategies, such as modeling, have been recognized in the literature to produce metacognitive growth (Sandi-Uren et al., 2011; Thomas & McRobbie, 2013; Zohar & David, 2009). Learning gains and perceptions of metacognition are complex and perhaps other factors played a role in the results, but it is possible that a revision of the conceptual framework to include the potential of the modeling exercises to affect change was validated by the study.

Limitations of the Study

The sampling procedure limited the methodology of this study. Using a convenience sampling of the researcher's classes rather than random sampling limited the generalizability of the findings to the broader population of high school chemistry students. The study was limited to a sample from one large public high school with majority high SES in the Southeastern United States. The results of this study were limited to the small variety of participants since all were enrolled in a specific level of chemistry, honors chemistry, and to a small sample size ($N_{control}$ = 26, $N_{experimental}$ = 22). A larger sample size could have aided in establishing statistically significant findings in learning gains and survey subscale two.

The participants had common enrollment in honors chemistry at a highly competitive high school so could be characterized as high achieving students possibly with well-honed skills of metacognition already in place. The similarity of the participants limits the generalization of results. The study was conducted during a time when a pandemic affected school procedures since students were present in class virtually and face-to-face. This external factor affected collection of data and social interaction.

Data was not collected on the specific demographics of the participants therefore the description of the participants was defined as roughly equivalent to the overall population of the school. This omission limited the specificity of the population description.

Additionally, a qualitative or mixed methods study, incorporating the data contained in the student responses to the Metacognitive Map over the five model activities, may provide further understanding of the experimental group in the present study and reduce the limitations of a quantitative research methodology.

The choice of MCAI for adaptation was hindered by the lack of validation of internal factors by factor analysis in the original survey. Also, the MCAPI adaptation was limited in validity of subscale one questions and subscale two questions that could have been answered in part by interviews of students regarding the instrument.

The MCAPI was not given prior to the treatment to both groups to avoid exposure to metacognitive concepts before the treatment of direct guidance was delivered to the experimental group. However, not collecting baseline data on metacognitive awareness of both groups limited the comparison between groups and eliminated comparisons for both groups between pre and post experiencing of the modeling exercises.

Not all conditions documented in previous research to affect metacognitive growth, content acquisition or development of the SEP modeling skill were included in the present study. Longer length of time for metacognitive cultivation is supported in the literature (Seraphin et al., 2012; Thomas & McRobbie, 2013; Graham et al., 2019) for example. Measurement of content acquisition by learning gains specifically tied to misconceptions may have limited the comparison of full content acquisition in the area of solution chemistry; inclusion of a summative evaluation comparison could have revealed an advantage conferred upon the experimental group in achievement.

Future Research

Future research could be designed for longer treatment time for metacognitive cultivation and applied to multiple science process skills or multiple SEPs. Secondly, the study could be replicated with more participants and in a time of school protocols A larger, more diverse population could contribute understanding of this topic and benefit the field of chemistry instruction. A study could be developed to also address the impact of modeling on metacognition in comparison to the direct cultivation of metacognition so as to answer some speculations which arose from the findings of this study.

Implications to the High School Chemistry Classroom

The findings of the study and the experience of conducting it were of immense benefit to the inform the instruction of the researcher. The modeling cycle implemented within the Formative platform was so successful and should be imparted in that manner going forth. The direct instruction of metacognition by PowerPoint and the cultivation induced by the Metacognitive Maps could be applied to other performance measures early in the year to develop metacognitive thinking processes. The MCAPI survey could be used to heighten awareness of metacognitive thinking processes and value of metacognition and thus contribute to the academic toolbox of the high school students towards achievement in arduous courses in high school and beyond.

The value of each, modeling in chemistry and direct metacognitive instruction, was demonstrated in this study. Contextualizing metacognitive instruction within a content skill was shown to be powerful for the development of the skill. Additionally, the strength of modeling to elicit ME and to lead toward development of metacognitive practices seem to be revealed in the data although that was not a quest of the study. Modeling exhibited ability to reduce misconceptions and increase content acquisition.

The study results recommend that metacognitive instruction be integrated into specific content or into content skills for mutual benefit of skill and metacognitive practices. Modeling as a practice is strongly recommended to enhance the learning of chemistry, elimination of misconceptions and to contribute to metacognitive development.

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Appendix

A.

PARENTAL CONSENT FORM WITH CHILD ASSENT STATEMENT

Title of Research Study: Metacognition and Modeling in Chemistry Instruction

Researcher's Contact Information: Meri Laird Cain Meri.Cain@cobbk12.org

Dear Parent:

Your child is being invited to take part in a research study conducted by Meri Cain of Kennesaw State University. Before you decide to allow your child to participate in this study, you should read this form and ask questions if you do not understand. Your decision to participate or not participate in this research will have no bearing on your student's grades or class standing. The study is not related to their relationship with the instructor or school and cannot / will not affect the relationship with the instructor or with the school.

Description of Project

The purpose of the study is **to investigate the benefit of directly teaching students about metacognition and of guiding students to reflect about metacognitive activities on the construction of chemistry models and on learning gains in chemistry.**

Explanation of Procedures

Students will have a pre-test and post-test (this is a normal part of the course work) on solution chemistry.

Students will be considered in control groups or experimental groups based on class sections. Students in the experimental groups will have a short presentation about metacognition delivered using PowerPoint and will use metacognitive guides as they work on chemistry modeling. (Students, in the control groups, who do not see the Metacognitive Presentation and use the metacognitive guides as part of the study will do so in the next unit ensuring all students learn about metacognition.)

Students will practice chemistry modeling based on chemical phenomenon and models will be graded (this is a normal part of the course work). Students will take a metacognitive survey. Data from the guides, the models, the tests and the survey will be used in the study although names will be concealed.

Time Required

Additional tasks to regular course work will take 10 minutes on 5 different days during a 3-week unit. Both control and experimental groups will use metacognitive guides either in this unit, associated with the study, or in the next unit.

Risks or Discomforts

There are no known risks or discomforts.

Benefits
Students may benefit from learning about metacognition and reflecting upon their own metacognitive experiences.

Confidentiality
The results of this participation will be confidential. Names will be concealed from all materials used in the study. Students will be assigned a study I.D. to label all materials used in place of a name. The study I.D. will allow for linking of data for analysis but protect the identity of the students. All of the data will be stored in secure password protected files.

Use of Online Surveys (if applicable)
Email addresses nor I.P. Addresses will be collected.

Inclusion Criteria for Participation
Students are enrolled in the researcher's classes and are in the grade level of 10^{th} – 12^{th} grade.

Parental Consent to Participate

I give my consent for my child, ____, to participate in the research project described above. I understand that this participation is voluntary and that I may withdraw my consent at any time without penalty. I also understand that my child may withdraw his/her assent at any time without penalty.

____ ___/___/2021
Signature of Parent or Authorized Representative, Date

____ ___/___/2021
Signature of Investigator, Date

PLEASE SIGN TWO COPIES OF THIS FORM, KEEP ONE AND RETURN THE OTHER TO THE INVESTIGATOR
Research at Kennesaw State University that involves human participants is carried out under the oversight of an Institutional Review Board. Address questions or problems regarding these activities to the Institutional Review Board, Kennesaw State University, 585 Cobb Avenue, KH3417, Kennesaw, GA 30144-5591, (470) 578-7721.

CHILD/ Student ASSENT STATEMENT

Child Assent to Participate

As your teacher, Ms. Meri Cain, I am inviting you to be in a research study about metacognition and modeling in chemistry. Your parent has given permission for you to be in this study, but you get to make the final choice. It is up to you whether you participate.

Your decision to participate or not participate in this research will have no bearing on your grades or class standing. The study is not related to your relationship with the instructor or school and cannot / will not affect the relationship with the instructor or with the school.

During the study, I will ask you to watch a metacognitive presentation, use your data from completed metacognitive guides, pretest and posttest scores, model rubric scores and your data from a metacognitive survey. See the details below:

Description of Project

The purpose of the study is **to investigate the benefit of directly teaching students about metacognition and of guiding students to reflect about metacognitive activities on the construction of chemistry models and on learning gains in chemistry.**

Explanation of Procedures

Students will have a pre-test and post-test (this is a normal part of the course work) on solution chemistry.

Students will be considered in control groups or experimental groups based on class sections. Students in the experimental groups will have a short presentation about metacognition delivered using PowerPoint and will use metacognitive guides as they work on chemistry modeling. (Students, in the control groups, who do not see the Metacognitive Presentation and use the metacognitive guides as part of the study will do so in the next unit ensuring all students learn about metacognition.)

Students will practice chemistry modeling based on chemical phenomenon and models will be graded (this is a normal part of the course work). Students will take a metacognitive survey. Data from the guides, the models, the tests and the survey will be used in the study although names will be concealed.

Time Required

Additional tasks to regular course work will take 10 minutes on 5 different days during a 3-week unit. Both control and experimental groups will use metacognitive guides either in this unit, associated with the study, or in the next unit.

Risks or Discomforts

There are no known risks or discomforts.

Benefits
Students may benefit from learning about metacognition and reflecting upon their own metacognitive experiences.

Confidentiality
The results of this participation will be confidential. Names will be concealed from all materials used in the study. Students will be assigned a study I.D. to label all materials used in place of a name. The study I.D. will allow for linking of data for analysis but protect the identity of the students. All of the data will be stored in secure password protected files.

Use of Online Surveys (if applicable)
Email addresses nor I.P. Addresses will be collected.

Inclusion Criteria for Participation
Students are enrolled in the researcher's classes and are in the grade level of 10^{th} – 12^{th} grade.

Students, you do not have to answer any question you do not want to answer or do anything that you do not want to do. Everything you say and do will be private, and your parents will not be told what you say or do while you are taking part in the study. When I tell other people what I learned in the study, I will not tell them your name or the name of anyone else who took part in the research study.

If anything in the study worries you or makes you uncomfortable, let me know and you can stop. No one will be upset with you if you change your mind and decide not to participate. You are free to ask questions at any time and you can talk to your parent any time you want. If you want to be in the study, sign or print your name on the line below:

____ ___/___/2021
Child's/Student's Name and Signature, Date

Check which of the following applies *(completed by person administering the assent.)*

☐ Child/Student is capable of reading and understanding the assent form and has signed above as documentation of assent to take part in this study.

☐ Child is not capable of reading the assent form, but the information was verbally explained to him/her. The child signed above as documentation of assent to take part in this study.

____ ___/___/2021
Signature of Person Obtaining Assent, Date

B. Instruction in Metacognition, **Metacognitive MAP** M. Cain (2019)

Metacognition MAP*
thinking about thinking
Planning ● Monitoring ● Evaluating

name: ______________________________________ period: _____ date: ______/______/____________

Task: Creating and Labeling/Keying a Model to Represent a Phenomenon in Chemistry

Making a plan
What do I know about models and creating a model in science?
How could I describe the instructional goal of my teacher in having the class draw models in chemistry?
What are the steps I need to take to successfully create a model based on a phenomenon in chemistry?
Actively monitoring
What strategies am I using that are working to help me create a model? What is one strategy I have discarded?
While creating the model, what is most challenging and what is most confusing to me?
What other resource could I be using to complete this task?
Practice evaluating
To what extent did I successfully accomplish the goal of the task?
If I were the teacher, what would I identify as one strength of my work; what would I identify as one flaw in my work?
What are the sequential steps I could take to create a model of another chemistry phenomenon? How could I teach modeling to another student?

* based on the work of Tanner, K. (2012). Promoting student metacognition. *CBE—Life Sciences Education, 11,* 113-120.

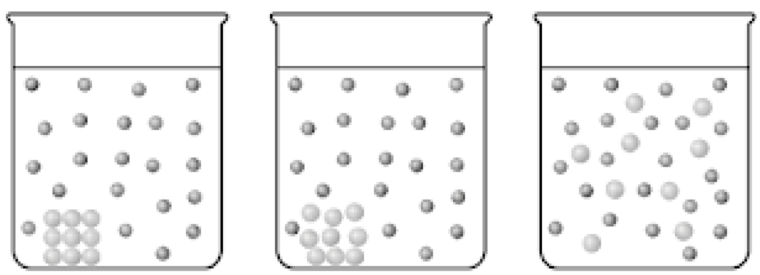
C. Pretest/Posttest on Solutions Misconceptions

Solutions Misconceptions Pre-Test/Posttest

1. When sugar $C_{12}H_{22}O_{11}$ dissolves in water, it:
a. melts into a liquid and forms a homogenous mixture with water
b. breaks apart into smaller particles, invisible to the naked eye, to form homogenous mixture with water
c. reacts to form a completely new substance that can disappear in water
d. joins with water molecules to form a new invisible substance
(Queensland Science Teachers, 2000)

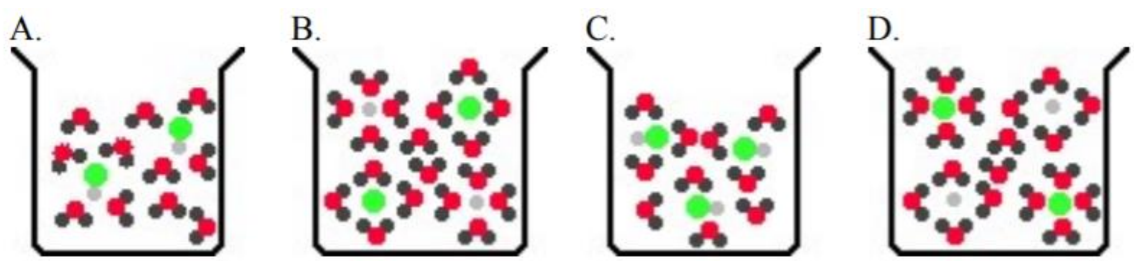
2. The process of solute particles being surrounded by solvent particles is known as _______.
e. melting
f. solvation
g. fusion
h. dehydration
(New Jersey Center for Teaching and Learning, 2014)

3. The equation that describes the process represented in the model is:

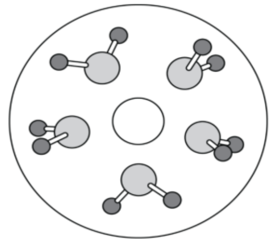


a. $C_{12}H_{22}O_{11}\ (s) \rightarrow C_{12}H_{22}O_{11}\ (l)$
b. $C_{12}H_{22}O_{11}\ (l) \rightarrow C_{12}H_{22}O_{11}\ (s)$
c. $C_{12}H_{22}O_{11}\ (s) \rightarrow C_{12}H_{22}O_{11}\ (aq)$
d. $C_{12}H_{22}O_{11}\ (s) + 12O_2(g) \rightarrow 12CO_2(g) + 12H_2O(l)$

4. Which of the images below best represents an ionic compound like KBr dissolved in water?



(College Board, n.d.)



5. A solid compound of a group 1 (alkali) metal and a group 17 (halogen) element dissolves in water. The diagram above represents one type of solute particle present in the solution. Which of the following identifies the solute particle and best helps explain how the solute particle interacts with water molecules?

- **a.** The particle is a negative ion and water molecules surround it in a hydration ring.
- **b.** The particle is a positive ion, and water molecules surround it in a hydration ring.
- **c.** The particle is a ionic molecule and water molecules surround it in a hydration ring.
- **d.** The particle is a covalent molecule and water molecules surround it in a hydration ring.

(College Board, n.d.)

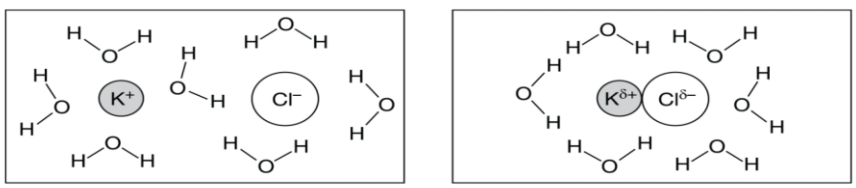


Diagram 1 Diagram 2

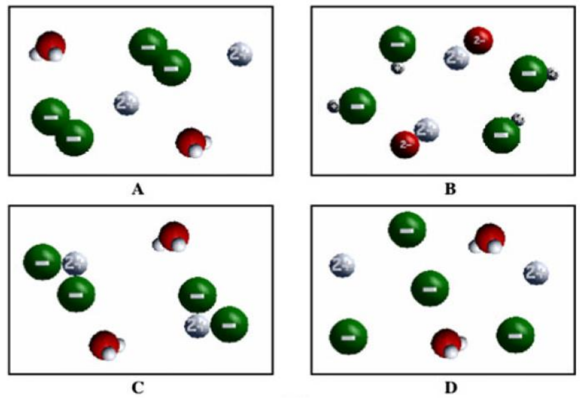
6. Which of the diagrams above best represents the interactions that are responsible for the relatively large solubility of KCl crystals in water, and why?

- **a.** Diagram 1, because strong ion-dipole interactions between KCl and water help to dissociate the solute.
- **b.** Diagram 1, because strong London dispersion forces between the K+ and Cl− ions and water replace the weak London dispersion forces between two water molecules.
- **c.** Diagram 2, because strong dipole-dipole forces between KCl and water help to separate the KCl units within the crystals.
- **d.** Diagram 2, because the hydrogen bonds between water molecules expand to accommodate the KCl particles and pull them into solution.

(College Board, n.d.)

7. Which of these equations best describes what happens when solid $MgCl_2$ dissolves in water?
   a. $MgCl_2$(s) → $MgCl_2$ (aq)
   b. $MgCl_2$(s) → $MgCl_2$ (l)
   c. $MgCl_2$(s) → Mg^{2+}(aq) + 2Cl^- (aq)
   d. $MgCl_2$(s) → $Mg^{2+($aq) + Cl^-_2 (aq)
   (Naah & Sanger, 2012)

8. Which of these diagrams best describes what happens when solid $MgCl_2$ dissolves in water?



(Naah & Sanger, 2012)

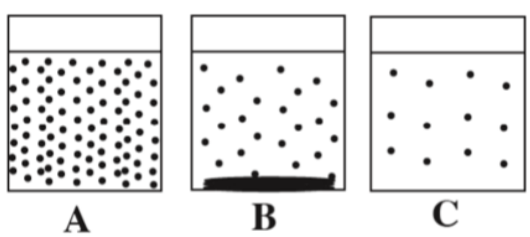
9. Which statement describes an electrolyte?
   a. An electrolyte conducts an electric current as a solid and dissolves in water.
   b. An electrolyte conducts an electric current as a solid and does not dissolve in water.
   c. When an electrolyte dissolves in water, the resulting solution conducts an electric current.
   d. When an electrolyte dissolves in water, the resulting solution does not conduct an electric current

(Regents, n.d.)

10. Why is potassium nitrate classified as an electrolyte?
    a. It is a molecular compound.
    b. It contains a metal.
    c. It can conduct electricity as a solid.
    d. It releases positive and negative ions in an aqueous solution.

(Regents, n.d.)

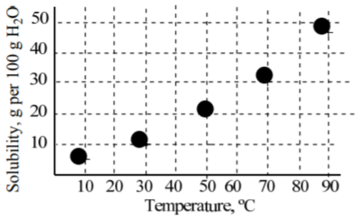
11. There are different concentrations of sugar solutions in beakers A, B, and C. One solution is saturated, one unsaturated and one supersaturated. The dots represent the sugar molecules; water is not shown. Which is correct?



    a. A is saturated; B is unsaturated; C is supersaturated
    b. A is unsaturated; B is supersaturated; C is saturated
    c. A is supersaturated; B is unsaturated; C is saturated
    d. A is supersaturated; B is saturated; C is unsaturated

(Adadon & Savasci, 2012)

12. The solubility of $KClO_3$ at several temperatures is shown in the accompanying diagram.



A student mixes 10.0 g of $KClO_3$ with 45.0 g of H_2O and stirs it for a long time at 60 ˚C until the solution is completely clear then allows it to cool slowly to 20 ˚C where it remains clear. Which statement about the final clear mixture at 20 ˚C is correct?

a. It is a saturated solution.
b. It is an unsaturated solution and can be made saturated by decreasing the temperature.
c. It is an unsaturated solution and can be made saturated by increasing the temperature.
d. It is a supersaturated solution.

(American Chemical Society, n.d.)

13. The solubility of gases in water:

a. is independent of the temperature.
b. increases with increasing temperature.
c. decreases with increasing temperature.
d. Gases are not soluble in water.
e. none of the above

(New Jersey Center for Teaching and Learning, 2014)

14. Under which conditions is the solubility of oxygen gas in water the greatest?

	Pressure	Temperature
a.	high	high
b.	high	low
c.	low	high
d.	low	low

(American Chemical Society, n.d.)

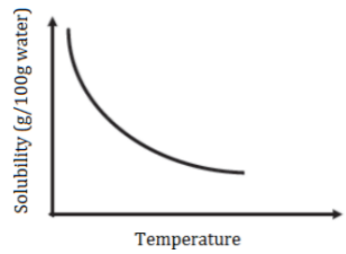
15. The bottler of a carbonated beverage dissolves carbon dioxide in water by placing carbon dioxide in contact with water at a pressure of 1 atm at room temperature. The best way to increase the amount of dissolved CO_2, would be to

a. increase the temperature and increase the pressure of CO_2.
b. decrease the temperature and decrease the pressure of CO_2.
c. increase the temperature without changing the pressure of CO_2.
d. decrease the temperature and increase the pressure of CO_2.
e. increase the pressure of CO_2 without changing the temperature

(New Jersey Center for Teaching and Learning, 2014)

16. The curve best represents the solubility curve for____at 25ºC
   a. LiBr
   b. $C_{12}H_{22}O_{11}$
   c. CO_2
   d. NaI

   (New Jersey Center for Teaching and Learning, 2014)



17. For which property is the value greater for a solution of a nonvolatile solute than for the pure solvent?
   a. boiling point
   b. freezing point
   c. triple point
   d. vapor

(American Chemical Society, n.d.)

18. Which of the following statements about colligative properties is FALSE?
   a. The boiling point of a solution is increased by the addition of salt.
   b. The freezing point of a solution is lowered by the addition of salt.
   c. The number of particles dissolved is not a factor.
   d. The identity of the solute is not a factor.
   e. All of the above statements are true

19. Compared to the boiling point and the freezing point of water at 1 atmosphere, a 1.0 M $CaCl_2(aq)$ solution at 1 atmosphere has a
   a. lower boiling point and a lower freezing point
   b. lower boiling point and a higher freezing point
   c. higher boiling point and a lower freezing point
   d. (4) higher boiling point and higher freezing point

(Regents, n.d.)

20. Which solute produces the highest boiling point in a 0.15 m aqueous solution?
   a. $CaCl_2$
   b. NaBr
   c. $CuSO_4$
   d. CH_3OH

(American Chemical Society, n.d.)

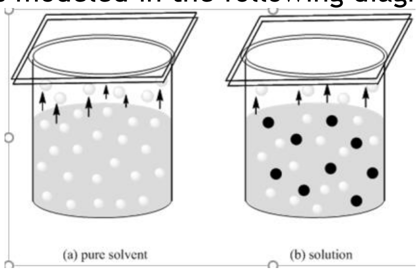
21. The normal boiling point and vapor pressure at 25 °C are measured for liquids in two flasks. Flask A contains pure water and flask B contains a 1.0 M aqueous NaCl solution.

Which flask contains the liquid with the higher boiling point?
Which flask contains the liquid with the least molecules of water vapor above the surface?

	Higher boiling point	Least molecules of water vapor
a.	Flask A	Flask A
b.	Flask A	Flask B
c.	Flask B	Flask A
d.	Flask B	Flask B

(American Chemical Society, n.d.)

22. Sugar is dissolved in water as modeled in the following diagram:



Which statement is true?

a. The vapor pressure for the solution is lower since less water is escaping the solution.
b. The vapor pressure for the solution is lower since less sugar is escaping the solution.
c. The vapor pressure for the solution is higher since more water is escaping the solution.
d. The vapor pressure for the solution is lower since more sugar is escaping the solution.

(Regents, n.d.)

D. Rubric to evaluate student models

Rubric for the Evaluation of Student Generated Particulate Models A. EDWARDS, M. CAIN, A. BAXLEY (2017)

Model feature(s)	4	3	2	1
Illustration of Particles	Student uses the appropriate representation (i.e., Lewis Structure, ball and stick, space filling model) of each of the chemical formula(e) of the molecules/atoms in the model	Student uses different geometric shapes to represent each different chemical formula in the model. A legend/key is also provided in the illustration	Student uses the chemical formula(e) of the molecules/atoms to represent the substance in the model	A drawing at the macroscopic level (no detail) is provided in student answer
Use of spacing And/or size	Spacing between particles is appropriate for the state of matter, energy/temperature, and attractive forces present in the sample	Spacing between particles is appropriate for **<u>two</u>** of the following regarding model: the state of matter, energy, temperature, and/or attractive forces present in the sample	Spacing between particles is appropriate for **<u>only one</u>** of the following regarding model: the state of matter,	Spacing in the model is same regardless the state of matter illustrated. Energy/temperature or attractive forces present in the sample are not addressed
Use of motion/energy	Description of motion (vibrational, translational, rotational) is appropriate for the state of matter present and is appropriate for the energy/temperature present	Motion (vibrational, translational, rotational) is appropriate for the state of matter present and is appropriate for the energy/temperature present but is provided in words instead of as an aspect of the model	Motion (vibrational, translational, rotational) is appropriate for the state of matter present and is appropriate for the energy/temperature present but is provided in words instead of as an aspect of the model	Neither motion nor energy of particles is addressed in the model
Particle interaction	Orientation of particles shows a clear understanding of the forces of attraction/repulsion between particles. Additionally, appropriate intramolecular and bonding interactions are illustrated correctly	Orientation of particles shows a clear understanding of the forces of attraction/repulsion between particles. Minor errors are present regarding the bonding interactions	Both intramolecular and bonding interactions, but inconsistencies or minor errors are present with regards to both types of interactions	Major errors or inconsistencies in both intramolecular and bonding interactions in the model or the interactions between particles is not addressed in the illustration
Number of particles depicted	An accurate description of the number/relative amount of molecules present is depicted based on mole ratio or stoichiometric data	Some attempt at an accurate description of the number/relative amount of molecules present is depicted based on mole ratio or stoichiometric data (at least 50% correct)	Little attempt at an accurate description of the number/relative amount of molecules present is depicted based on mole ratio or stoichiometric data (at least 25% correct)	No attempt at an accurate description of the number/relative amount of molecules present is depicted based on mole ratio or stoichiometric data
Use of levels of representation	Macroscopic aspects meaningful/appropriate to the physical or chemical process are consistently depicted and are accurate	Many macroscopic aspects meaningful/appropriate to the physical or chemical process are depicted and are accurate. Omission of macroscopic aspects does not affect the overall understanding of the illustration	Few macroscopic aspects meaningful/appropriate to the physical or chemical process are depicted leading to significant difficulty in using/understanding the illustration	No macroscopic aspects meaningful/appropriate to the physical or chemical process are presented in the illustration
	Complete particle	***Basic Particle***	***Mixed***	***Descriptive***

*adapted from:

Merritt, J., & Krajcik, J. (2013). Learning progression developed to support students in building a particle model of matter. In *Concepts of matter in science education* (pp. 11-45). Springer, Dordrecht.

Merritt, J. D., Krajcik, J., & Shwartz, Y. (2008, June). Development of a learning progression for the particle model of matter. In *Proceedings of the 8th international conference on International conference for the learning sciences-Volume 2* (pp. 75-81). International Society of the Learning Sciences.

Ngai, C., Sevian, H., & Talanquer, V. (2014). What is this substance? What makes it different? Mapping progression in students' assumptions about chemical identity. *International Journal of Science Education*, *36*(14), 2438-2461.

Sevian, H., & Talanquer, V. (2014). Rethinking chemistry: A learning progression on chemical thinking. *Chemistry Education Research and Practice*, *15*(1), 10-23.

E. Instructions for Modeling Exercises as appeared in Formative

Model 1

Control Group instructions:

Another physical change of sugar $C_{12}H_{22}H_{11}(s)$ is shown below in the video clip.
This change pertains to our current study of solution chemistry.
After watching the video:

1. Write the equation to symbolically represent the macroscopic event on the video.
2. Draw a particle model of the process with two boxes showing before the solution is mixed and the final result.
3. All particles should be represented with symbols and a key included.
4. LABEL YOUR MODEL WITH YOUR I.D. #

Experimental Group instructions:

Another physical change of sugar $C_{12}H_{22}H_{11}(s)$ is shown below in the video clip.
This change pertains to our current study of solution chemistry.
After watching the video:

1. Write the equation to symbolically represent the macroscopic event on the video.
2. Draw a particle model of the process with two boxes showing before the solution is mixed and the final result.
3. All particles should be represented with symbols and a key included.
4. LABEL YOUR MODEL WITH YOUR I.D. #
5. *Complete the Metacognitive Map during # 12 and #13. UPLOAD TO TEAMS*

Initial model template

Show Your Work 6 pts

12 Equation and Particle models

Edit background

Select standards set

Revised Model template

Show Your Work 25 pts

13 REVISED: Equation and Particle models
LABEL YOUR MODEL WITH YOUR I.D. #

Edit background

Model 2: *only control group instructions shown*

Watch the class demo of potassium bromide added to water.

Show Your Work 6 pts

11 Draw a particulate model depicting the solvation of the ionic salt KBr in water.

1. Write the equation.
2. Use three panes to show different points in the process: before mixing, during the mixing and final result
3. Use symbols to represent particles and include a key.

Edit background

STOP here.
After class discussion of individual models, revise your model.

Show Your Work 25 pts

12 Equation and REVISED Particle models. LABEL with I.D. #

Edit background

Model 3: *only control group instructions shown*

Text Block

Observe the DEMO in class as 3 solids are mixed into water.

17 *Although there are no macroscopic differences observed, are there difference at the sub-microscopic level?*
We can represent the sub-microscopic differences that occur in different solutes when dissolved in water with particulate models. For each substance given, construct a particulate model of the final result when that substance is dissolved. Include a minimum of 3 solute particles. Use the beakers provided or upload your own drawing.

- Model 1: Fructose $C_6H_{12}O_6$
- Model 2: Potassium chloride
- Model 3: Potassium phosphate

1. Write the equations.
2. Represent all particles and include a key.

Edit background

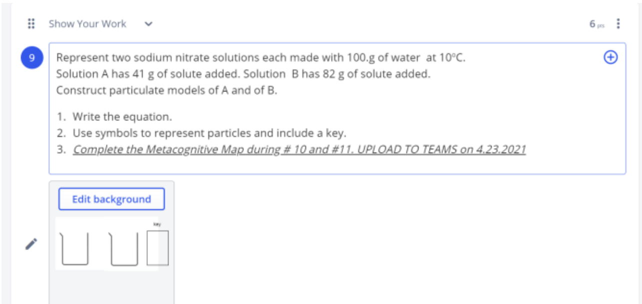
Show Your Work 25 pts

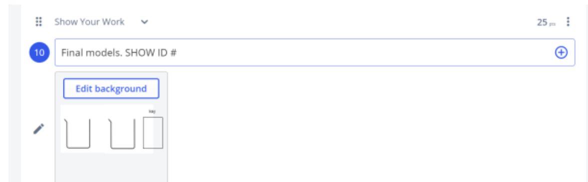
18 Revised models. Write I.D. #

1. Write the equations.
2. Represent all particles and include a key.

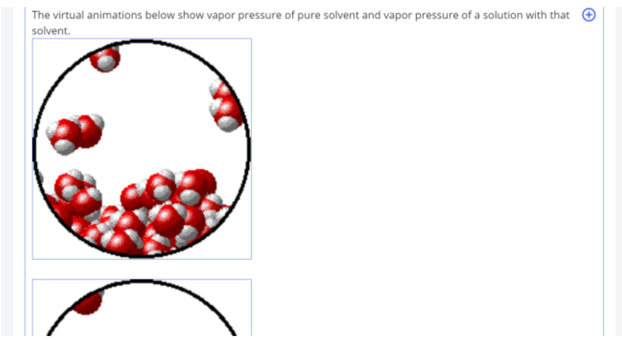
Edit background

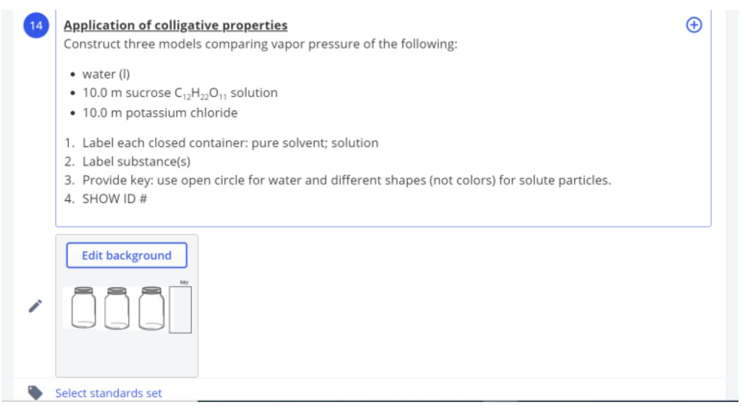
Model 4: *only experimental group instructions shown*

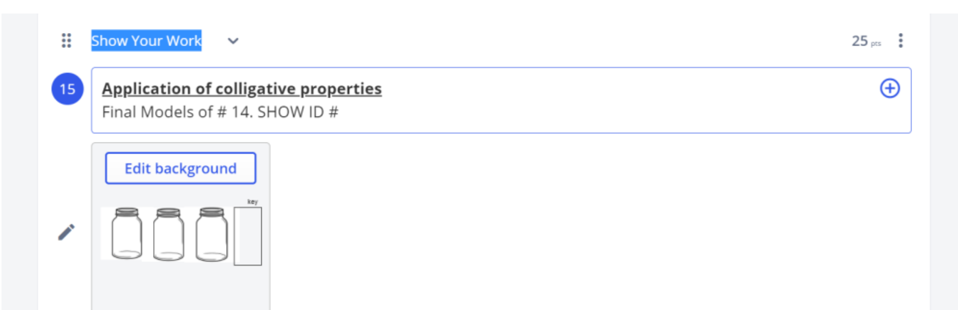




Model 5: *only control group instructions shown*

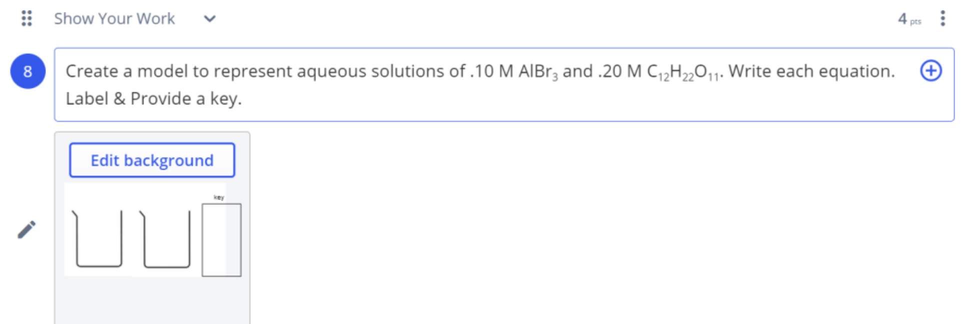






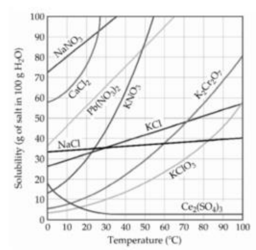
F. Unit Summative Questions # 8, 15, 24 on Model Construction

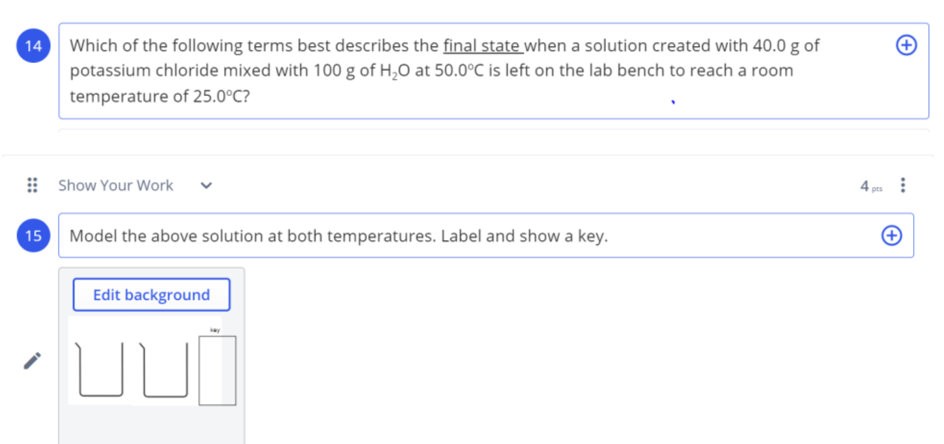
8 Dissolving of covalent and ionic solutes



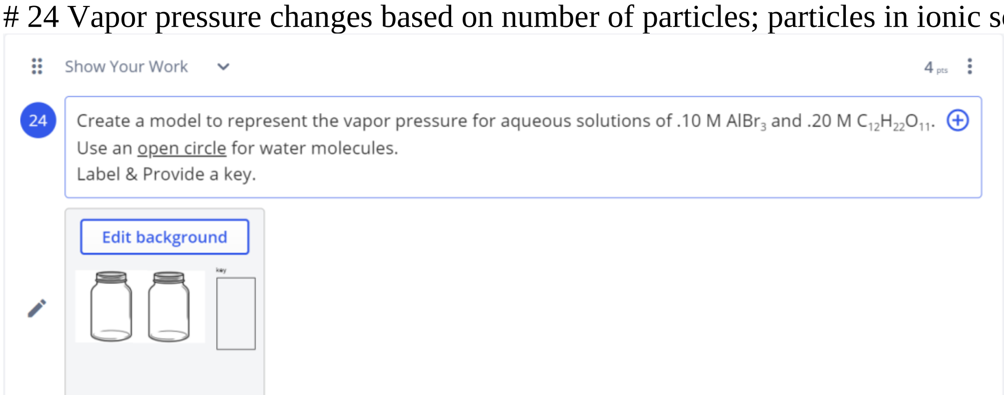
15 Saturation state of solutions using solubility table

Use the following image to answer questions 11-15.





24 Vapor pressure changes based on number of particles; particles in ionic solute.



G. Inventory assessing metacognition perception and activities*** M Cain (2019)

MCAPI **Metacognitive Activities and Perception Inventory** **MCain2019**

Subject: Chemistry 111 Grade Level: 11/12 Time Frame: _____

Information about you: Check ONE for each

Gender □ Male □ Female Average in course □ 95-100 □ 90-95 □ 80-89 □ 70-79 □ 60-69

Respond to each statement with the appropriate number from the response scale.

	Statements	1- Strongly Disagree 2- Somewhat Disagree 3- Slightly Disagree 4- Slightly Agree 6- Somewhat Agree 5- Strongly agree					
		1	2	3	4	5	6
Perception of value of metacognitive activity and strategies							
Q 1	I was helped by the presentation to look at academic tasks differently.						
Q 2	I will use some of the strategies to approach my academic work differently.						
Q 3	I understood the ideas presented about metacognition.						
Q 4	I think using metacognitive strategies could help me to learn.						
Q 5	I have already used a new strategy in my academic tasks after working on metacognition.						
Q 6	I believe that the metacognitive strategies helped me with the task of modeling at the sub-microscopic level						
Perceptions/awareness of own metacognitive thinking process							
Q 7	I read the modeling activity instructions carefully to fully understand it and determine what the goal is.						
Q 8	When I do modeling activities, I try to learn more about the concepts so I can apply this knowledge to the test						
Q 9	I sort the observations I made of the phenomenon and determine what is relevant.						
Q 10	I try to relate the creation of my model to previous models I have created or models seen.						
Q 11	I clearly identify the goal of the modeling activity before attempting to create my model.						
Q 12	I consider what information needed might not be evident in the demonstration of the chemical phenomenon.						

Q 13	I try to double-check everything: my observations of the phenomenon, ratios of particles, particulate representation, appropriate symbols and keys and processes shown.						
Q 14	I use graphic organizers (diagrams, flow-chart) to better understand the chemistry concepts or processes.						
Q 15	I experience moments of insight or creativity when creating chemistry models						
Q 16	I jot down things I know that might help me create the model or with the chemistry concept before creating the model.						
Q 17	I find important relations between particles, particle quantities and particle placements before creating my model						
Q 18	I make sure that my finished model actually represents the chemical phenomenon and achieves the goal of the activity.						
Q 19	I plan how to create the model before I actually start drawing (even if it is a brief mental plan).						
Q 20	I reflect upon things I know are relevant to the chemical phenomenon and the chemistry concept.						
Q 21	I analyze the steps of my plan and the appropriateness of each step.						
Q 22	I attempt to break down the observation of phenomenon to find a starting point for my model.						
Q 23	I spend little time on creating a model for a concept that I have not been taught.						
Q 24	When I create a model, I omit thinking of concept before I attempt my drawing of the model.						
Q 25	Once I know how to draw the model, I put no more time in understanding the concepts involved.						
Q 26	I do not check to see if my model representations make sense.						
Q 27	If I do not know exactly how to represent the chemical phenomenon, I immediately start to draw something to turn in.						
Q 28	I start drawing my model without having read all the details of the activity and consulting my observations of the phenomenon.						

***Adapted from MCAI, Metacognitive Activities Inventory (Cooper & Sandi-Urena, 2009)

H. Subscales and components of MCAPI

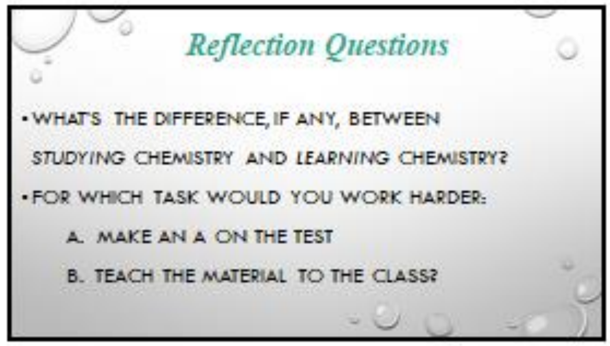
MCAPI Subscales 1 and 2 and Subscale 2 Components

Metacognitive Activities and Perception Inventory **MCain2019**

	Statements Subscale 1: Q1-Q6; Subscale 2: Q7-Q28	1- Strongly Disagree 2- Somewhat Disagree 3- Slightly Disagree 4- Slightly Agree 6- Somewhat Agree 5- Strongly agree 1	2	3	4	5	6
SUBSCALE 1: Perception of **value** of metacognitive activity and strategies							
Q 1	I was helped by the presentation to look at academic tasks differently.						
Q 2	I will use some of the strategies to approach my academic work differently.						
Q 3	I understood the ideas presented about metacognition.						
Q 4	I think using metacognitive strategies could help me to learn.						
Q 5	I have already used a new strategy in my academic tasks after working on metacognition.						
Q 6	I believe that the metacognitive strategies helped me with the task of modeling at the sub-microscopic level						
SUBSCALE 2: Perceptions/awareness of own **metacognitive thinking process**							
Making a Plan							
Q 7	I read the modeling activity instructions carefully to fully understand it and determine what the goal is.						
Q 11	I clearly identify the goal of the modeling activity before attempting to create my model.						
Q 16	I jot down things I know that might help me create the model or with the chemistry concept before creating the model.						
Q 17	I find important relations between particles, particle quantities and particle placements before creating my model						
Q 19	I plan how to create the model before I actually start drawing (even if it is a brief mental plan).						
Q 22	I attempt to break down the observation of phenomenon to find a starting point for my model.						
Q 24	When I create a model, I omit thinking of concept before I attempt my drawing of the model.						
Q 27	If I do not know exactly how to represent the chemical phenomenon, I immediately start to draw something to turn in.						
Q 28	I start drawing my model without having read all the details of the activity and consulting my observations of the phenomenon.						
Actively Monitoring							
Q 8	When I do modeling activities, I try to learn more about the concepts so I can apply this knowledge to the test						
Q 9	I sort the observations I made of the phenomenon and determine what is relevant.						
Q 10	I try to relate the creation of my model to previous models I have created or models seen.						
Q 12	I consider what information needed might not be evident in the demonstration of the chemical phenomenon.						
Q 14	I use graphic organizers (diagrams, flow-chart) to better understand the chemistry concepts or processes.						
Q 15	I experience moments of insight or creativity when creating chemistry models						
Q 23	I spend little time on creating a model for a concept that I have not been taught.						
Q 25	Once I know how to draw the model, I put no more time in understanding the concepts involved.						
Practice Evaluating							
Q 13	I try to double-check everything: my observations of the phenomenon, ratios of particles, particulate representation, appropriate symbols and keys and processes shown.						
Q 18	I make sure that my finished model actually represents the chemical phenomenon and achieves the goal of the activity.						
Q 20	I reflect upon things I know are relevant to the chemical phenomenon and the chemistry concept.						
Q 21	I analyze the steps of my plan and the appropriateness of each step.						

I. Metacognition Power Point

1



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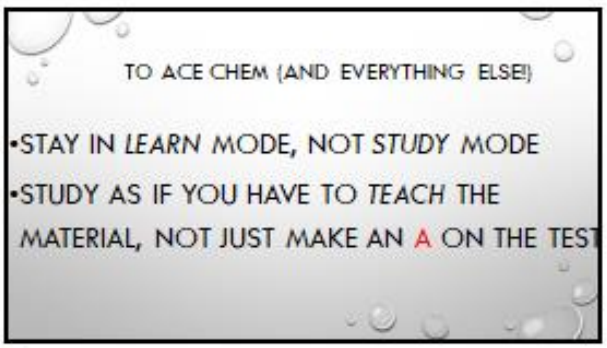

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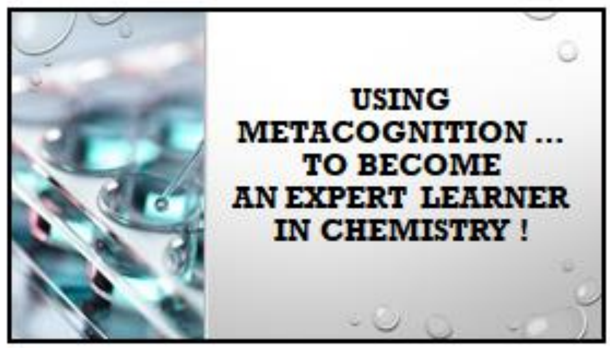

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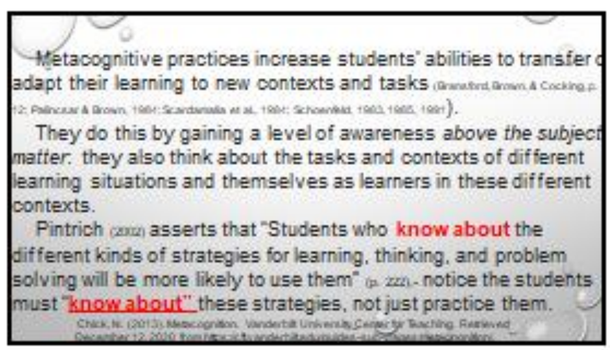
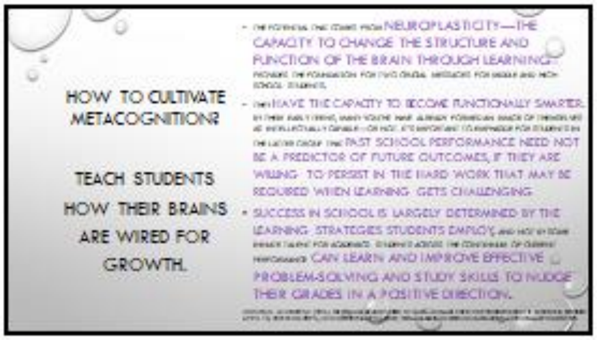
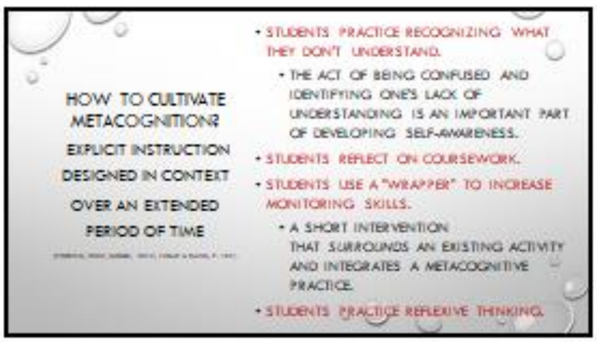



HOW TO CULTIVATE METACOGNITION?
TEACH STUDENTS HOW THEIR BRAINS ARE WIRED FOR GROWTH.
NEUROPLASTICITY—THE CAPACITY TO CHANGE THE STRUCTURE AND FUNCTION OF THE BRAIN THROUGH LEARNING
HAVE THE CAPACITY TO BECOME FUNCTIONALLY SMARTER.
PAST SCHOOL PERFORMANCE NEED NOT BE A PREDICTOR OF FUTURE OUTCOMES, IF THEY ARE WILLING TO PERSIST IN THE HARD WORK THAT MAY BE REQUIRED WHEN LEARNING GETS CHALLENGING
SUCCESS IN SCHOOL IS LARGELY DETERMINED BY THE LEARNING STRATEGIES STUDENTS EMPLOY,
CAN LEARN AND IMPROVE EFFECTIVE PROBLEM-SOLVING AND STUDY SKILLS TO NUDGE THEIR GRADES IN A POSITIVE DIRECTION.

7


HOW TO CULTIVATE METACOGNITION?
DRIVE THE BRAIN
ALTHOUGH EDUCATIONAL RESEARCH ON THE POWER OF METACOGNITION FOR INCREASING STUDENT LEARNING AND ACHIEVEMENT HAS BEEN AMASSING FOR SEVERAL DECADES, SCIENTISTS HA ONLY RECENTLY BEGUN TO PINPOINT THE PHYSICA CENTER OF METACOGNITION IN THE BRAIN.
RESEARCHERS AT THE UNIVERSITY COLLEGE LONDO HAVE DISCOVERED THAT SUBJECTS WITH BETTER METACOGNITION HAD MORE GRAY MATTER IN THE ANTERIOR (FRONT) PREFRONTAL CORTEX. STUDIES ARE ONGOING TO DETERMINE JUST HOW THIS BRAIN AREA CONTRIBUTES TO THE CRITICALLY-IMPORTANT SKILL OF METACOGNITION.

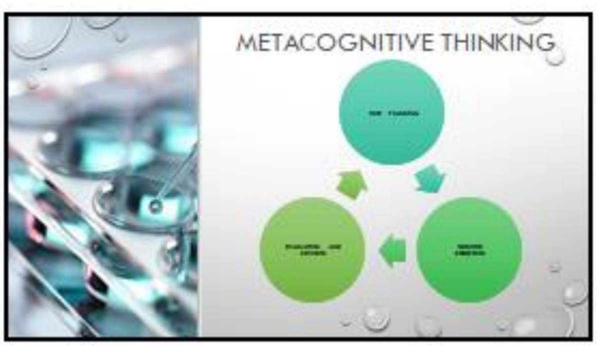
8


HOW TO CULTIVATE METACOGNITION?
EXPLICIT INSTRUCTION DESIGNED IN CONTEXT OVER AN EXTENDED PERIOD OF TIME
STUDENTS PRACTICE RECOGNIZING WHAT THEY DON'T UNDERSTAND.
THE ACT OF BEING CONFUSED AND IDENTIFYING ONE'S LACK OF UNDERSTANDING IS AN IMPORTANT PART OF DEVELOPING SELF-AWARENESS.
STUDENTS REFLECT ON COURSEWORK.
STUDENTS USE A "WRAPPER" TO INCREASE MONITORING SKILLS.
A SHORT INTERVENTION THAT SURROUNDS AN EXISTING ACTIVITY AND INTEGRATES A METACOGNITIVE PRACTICE.
STUDENTS PRACTICE REFLEXIVE THINKING.

9


How can WE cultivate metacognition in Chemistry 111?
HOW TO CULTIVATE METACOGNITION?
EXPLICIT INSTRUCTION DESIGNED IN CONTEXT OVER AN EXTENDED PERIOD OF TIME
EXPLICIT INSTRUCTION:
INTRODUCTION TO METACOGNITION
METACOGNITIVE GUIDANCE:
CULTIVATE METACOGNITIVE THINKING
METACOGNITIVE MAPS
NOTE
REFLECT
CONTEXT:
MODELING SKILL IN CHEMISTRY
DEVELOP SKILL
MASTER CONCEPTS
TIME: 2 WEEK SOLUTIONS UNIT

10


METACOGNITIVE THINKING

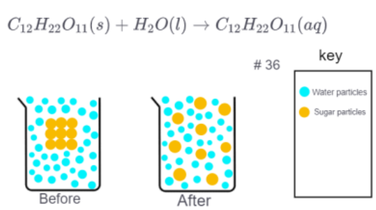
11

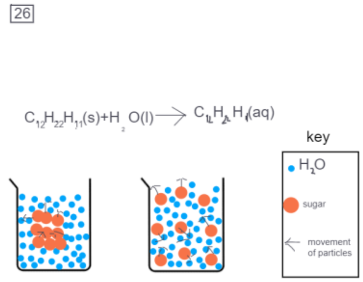

METACOGNITIVE THINKING
Metacognitive Map

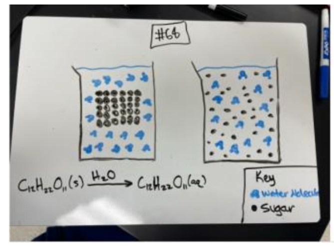
12

J. Model Example Responses: *control group **experimental group

Model 1:

* 

* 

** 

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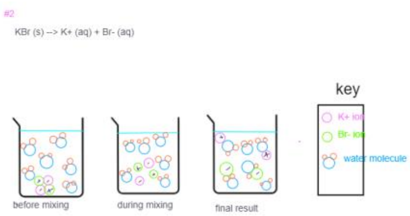
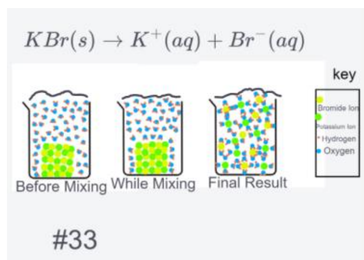
* 

* 

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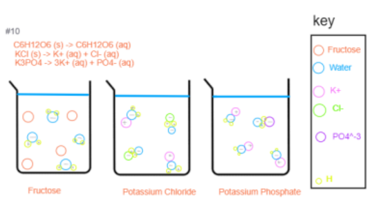
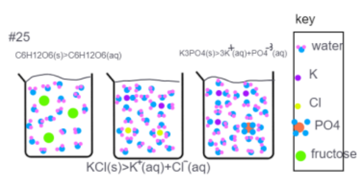
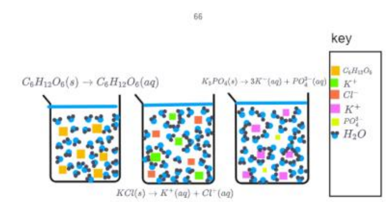
* 

* 

** 

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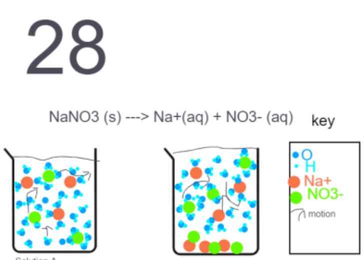
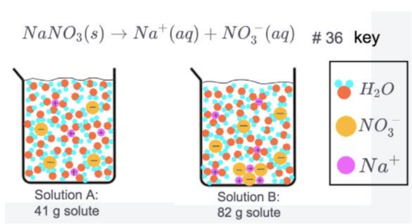
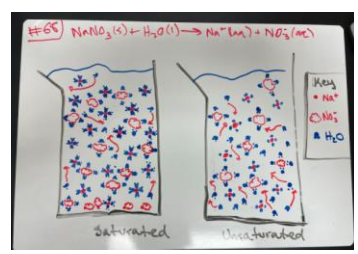
* 

* 

** 

Model 5:

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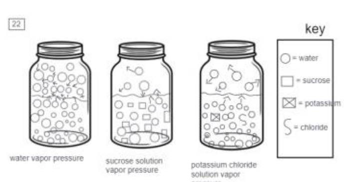
* 

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